AD-A047 969 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 6/6
ENVIRONMENTAL NOISE IMPACT ANALYSIS FOR ARMY MILITARY ACTIVITIE--ETC(U)
NOV 77 R J GOFF, E W NOVAK
UNCLASSIFIED CERL-TR-N-30 NL

1 OF 2
ADA047969

(12)
B.S.

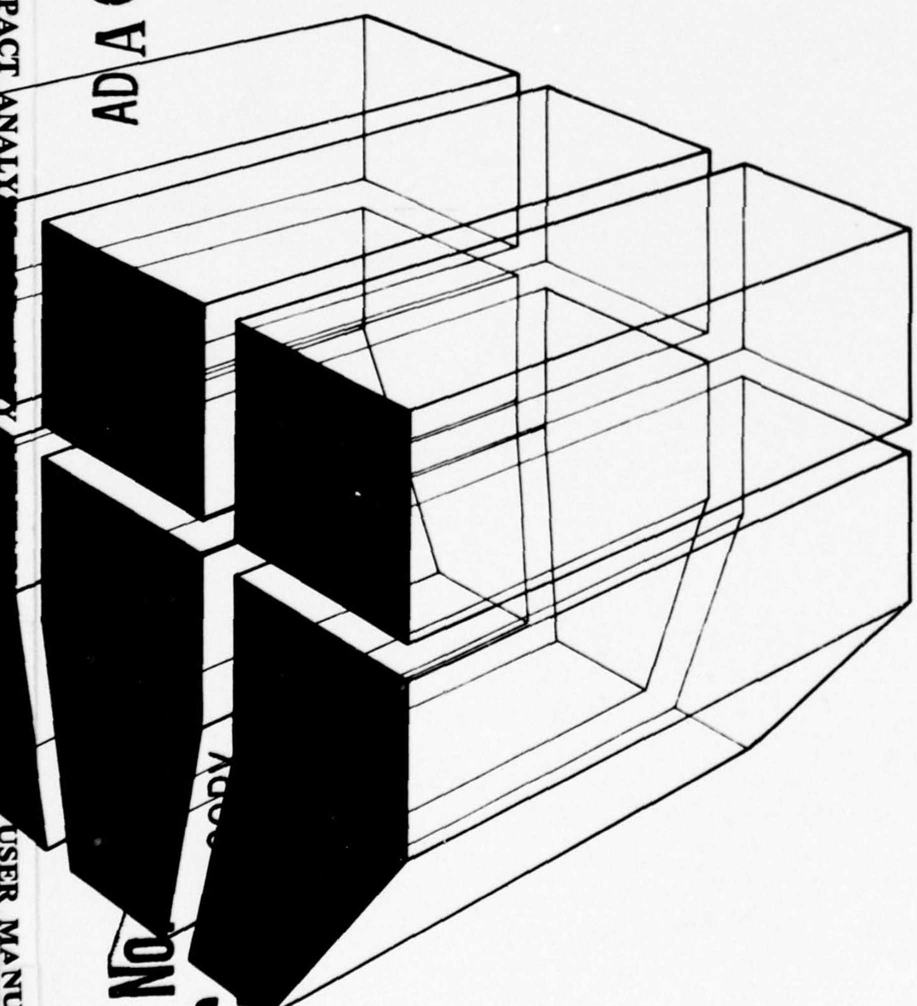
construction
engineering
research
laboratory

TECHNICAL REPORT N-30
November 1977
Procedures for Evaluating Environmental Impacts
of All Army Military Programs

T.R. N-30 ENVIRONMENTAL NOISE IMPACT ANALYSIS USER MANUAL

AD A047969

ENVIRONMENTAL NOISE IMPACT ANALYSIS FOR ARMY MILITARY ACTIVITIES: USER MANUAL



by
R. J. Goff
E. W. Novak

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) CERL-TR-N-30	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) ENVIRONMENTAL NOISE IMPACT ANALYSIS FOR ARMY MILITARY ACTIVITIES: USER MANUAL.		5. TYPE OF REPORT & PERIOD COVERED (9) FINAL rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) R. J./Goff E. W./Novak		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. Box 4005 Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 21 T WU 4A1621A896-01-001
11. CONTROLLING OFFICE NAME AND ADDRESS	(11)	12. REPORT DATE Nov[redacted]977
		13. NUMBER OF PAGES 118 (12) 120p.
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

per

(16) 4A162121A896 (17) 01

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from National Technical Information Service
Springfield, VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

environmental noise levels
environmental impact assessment
noise emissions

405 279

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This manual presents the most current techniques for evaluating the environmental impact of noise emissions from proposed and ongoing Army activities. It is designed for use in conjunction with the CERL-developed computer systems to produce an integrated approach to environmental impact assessment.

The manual provides the methodology for determining and documenting environmental noise levels, procedures for interpreting these levels in terms of impact

Gu

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block 20 continued.

on the human environment, methods by which these impacts might be mitigated, and finally procedures to prepare comprehensive environmental noise impact assessments or statements in accordance with the Council on Environmental Quality (CEQ) Guidelines and AR 200-1.

ACCESSION for
White Section ☑
Buff Section ☐
UNANNOUNCED ☐
JUSTIFICATION

BY
DISTRIBUTION/AVAILABILITY CODES
Dist. AVAIL. and/or SPECIAL
A

FOREWORD

This investigation was performed for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A1621A896, "Environmental Quality for Construction and Operation of Military Facilities," Task 01, "Environmental Quality Management for Military Facilities," Work Unit 001, "Procedures for Evaluating Environmental Impacts for All Army Military Programs." The applicable QCR is 3.01.001. The OCE Technical Monitor is Mr. V. J. Gottschalk.

This manual was completed by the joint efforts of the Environmental Operations Team (ENO) and the Environmental Acoustics Team (ENA), Environmental Division (EN), U. S. Army Construction Engineering Research Laboratory (CERL). CERL personnel who contributed significantly to this work were Dr. Paul Schomer, Chief of ENA, and Ms. Susan Thomas, ENO.

Consultants who contributed to the early efforts of this work are Mr. Richard K. Miller, Dr. Kent C. Williams, and Dr. Clifford R. Bragdon.

Dr. R. K. Jain is Chief of EN. COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

TABLES (Cont'd)

FIGURES

FIGURES (Cont'd)

FIGURES (Cont'd)

FIGURES (Cont'd)

PRECEDING PAGE BLANK-NOT FILMED

ENVIRONMENTAL NOISE IMPACT ANALYSIS FOR ARMY MILITARY ACTIVITIES: USER MANUAL

1 INTRODUCTION

Objective

The objective of this manual is to provide quantitative procedures for evaluating the environmental noise impact from Army activities. This evaluation will be used in the preparation of Environmental Impact Assessments/Statements (EIAs/EISs) in accordance with the eight-point guidelines established by the Council on Environmental Quality (CEQ)[1] and AR 200-1.[2] This manual presents a systematic approach based on the philosophy that noise descriptors, measurement and prediction methods, and evaluation criteria should be as uniform and simple as possible. It is designed for use with the CERL developed computer systems to provide an integrated approach to environmental impact assessment.

It must be stated that the extent to which this manual can be used depends on numerous factors—technical background of the user, time and funds available for the analysis, and complexity of the project being assessed. Some Army personnel can use its step-by-step procedures to draft the actual assessment, while other non-technical personnel can use guidelines to determine which aspects of the assessment can be performed in-house and which aspects require outside assistance. In the case of outside work, by using this manual, the exact work required can be specified, thus making contracts more economical and the results more productive.

The interpretation of environmental impact with respect to specific noise levels that are contained in this manual does not represent official DA policy. As a result, all noise-relevant EISs should be coordinated with the user's major command and the Department of the Army Environmental Office.

[1] "Preparation of Environmental Impact Statements: Guidelines," *Federal Register*, Vol 38, No. 147, Part II (August 1, 1973), pp 20550-20562.

[2] AR 200-1, *Environmental Protection and Enhancement* (Department of the Army, 28 December 1976).

Background

Legislative Requirements

The National Environmental Policy Act (NEPA-PL 91-190), passed in 1969, requires Federal agencies, before beginning a major project or activity, to prepare an EIA to determine how the quality of the human environment might be affected. If the environmental effects are either significant or environmentally controversial, NEPA requires a more detailed analysis of the activity, its effects, and possible alternatives, in the form of an EIS.

As a result of NEPA, the Department of the Army (DA) established its own environmental program, with detailed guidance contained in DA AR 200-1, "Environmental Protection and Enhancement."

In addition to DA, many other Federal, state, and local agencies adopted environmental programs in the form of legislation, assessment requirements, and EIA/EIS review procedures. Since solid waste, air, and water pollution have long been recognized as serious forms of pollution, they were the major concern of many of these actions; however, environmental noise has recently been addressed specifically as a pollutant in many of these programs and directives.

Presently, 19 states and the District of Columbia have noise impact requirements. In addition, many city and county governmental units (approximately 30 percent of cities with populations greater than 10,000) have instituted environmental review procedures for both public and private projects.

While the clearing house or coordinator for Federal noise programs is the Environmental Protection Agency's Office of Noise Abatement and Control, other Federal agencies have expertise in noise pollution and legal authority to comment on and review impact statements. These include:

1. Department of Commerce/National Bureau of Standards

2. Department of Health, Education, and Welfare

3. Department of Housing and Urban Development

4. Department of Labor

5. Department of Transportation

6. National Aeronautics and Space Administration.

Assessment Guidelines

The Council on Environmental Quality (CEQ) was established by NEPA and given the responsibility of monitoring the nation's environment, developing new environmental enhancement policies, and coordinating Federal environmental efforts. In fulfilling these responsibilities, CEQ has issued guidelines outlining the following eight essential points to be covered within an EIS:[3]

1. A description of the proposed action, a statement of its purpose, and a description of the project's environmental setting.

2. The relationship of the proposed action to land-use plans, policies, and controls for the affected area.

3. The probable impact of the proposed action on the environment.

4. Alternatives to the proposed action.

5. Any probable adverse environmental effects that cannot be avoided and how avoidable impacts will be mitigated.

6. The relationship between local short-term uses of the environment and the maintenance and enhancement of long-term productivity.

7. Any irreversible and irretrievable commitments of resources (both natural and cultural).

8. An indication of what other interests and considerations of Federal policy are thought to offset the adverse environmental effects identified.

Although these guidelines were specifically designed for the EIS, most of these elements should be discussed in EIAs, but in less detail. For example, consider Step 4. If an EIA indicates that the preferred course of action results in no significant impact and is not environmentally controversial, there is no need to examine other alternatives. In any event, these guidelines will be used by this manual as the basis for the noise EIA/EIS. DA PAM 200-1[4] provides specific guidance with regard to DA actions.

[3]"Preparation of Environmental Impact Statements: Guidelines," *Federal Register*, Vol 38, No. 147, Part II (August 1, 1973), pp 20550-20562.

Use of the Environmental Impact Computer System (EICS)

In specific response to all these directives and legal requirements, the EICS was developed by the U.S. Army Construction Engineering Research Laboratory (CERL) to help identify potential environmental impacts of major Army projects or programs. Army military programs are grouped into nine functional areas and are then related to environmental attributes to determine possible impact. Environmental attributes are grouped into 13 technical specialties: Ecology; Health Science; Air Quality; Surface Water; Groundwater; Sociology; Economics; Earth Science; Land Use; Noise; Transportation; Aesthetics; and Energy and Resource Conservation.

The specific attributes related to noise are human health, physiological maintenance, sleep performance, aural communication, television/radio communication, annoyance/disruption of task performance, and land-use incompatibility and integrity. Controversial attributes include disruption of human activity, and property value depreciation.[5]

Figure 1 is an example of information provided by the EICS for analyzing possible noise impact from a proposed activity. This output is based on answers to sets of input questions found in various Army function-oriented user's manuals.[6-9] The A, B, C scores (defined below) in the matrix indicate how the activities will impact the attributes.

[4]*Handbook for Environmental Impact Analysis*, Pamphlet No. 200-1 (Department of the Army, April 1975).

[5]These categories were designed to meet requirements listed in "Preparation of Environmental Impact Statements: Guidelines," *Federal Register*, Vol 38, No. 147, Part II (August 1, 1973), pp 20550-20562.

[6]L. V. Urban, H. E. Balbach, R. K. Jain, E. W. Novak, and R. E. Riggins, *Computer-Aided Environmental Impact Analysis for Construction Activities: User Manual*, Technical Report E-50/ADA008988 (U.S. Army Construction Engineering Research Laboratory [CERL], March 1975).

[7]R. E. Riggins and E. W. Novak, *Computer-Aided Environmental Impact Analysis for Mission Change, Operations and*

Activity *	Attributes *									
	1	2	3	4	5	6	7	8	10	11
10	C	C	C	C	C	C	C		C	
20	C	C	C	C	C	C	C		C	
30	C	C	C	C	C	C	C	C	C	C
50	A	A	A	A	A	A	A	A	A	A
60	C	C	C	B	B	B	B		C	
61	C	C	C	C	C	C	C		C	
62	C	C	C	C	C	C	C		C	
63	C	C	C	C	C	C	C		C	
64	A	A	C	C	C	C	C		C	
65	C	C	A	A	A	A	C		C	
70	C	C	C	C	C	C	C		C	
71	B	B	B	B	B	B	B		C	
80	C	C	C	C	C	C	C		C	
81	C	C	C	C	C	C	C		C	
83	C	C	C	C	C	C	C		C	
86	C	C	C	C	C	C	C		C	
100	C	C	C	C	C	C	C		C	
110	C	C	C	C	C	C	C		C	

*** Since the Matrix Provides Only Activity and Attribute Numbers, Separate Lists of the Corresponding Names Are Also Provided to the User.**

Figure 1. Example of EICS output.

A — Definitely consider this attribute as being potentially impacted by the activity in almost all cases.

B — Possible effect in many cases; requires consideration.

C — Impacts may occur in special cases.

Blank — Without knowing further project details, it is not possible to predict the likelihood of impact.

Use of the EICS involves a detailed analysis of this matrix output. If preliminary analysis shows that a significant noise problem does not exist, then efforts may be concentrated in other environmental areas; however, if the noise matrix reveals serious problems (existing or potential), this manual should be used to quantify the degree of impact on public health and welfare. Although it can be used without EICS, this manual has been designed to supplement the EICS analysis.

Maintenance, and Training Activities: User Manual, Technical Report E-85/ADA022698 (CERL, February 1976).

[8]E. W. Novak, S. E. Thomas, R. A. Mitchell, and R. E. Riggins, *Computer-Aided Environmental Impact Analysis for Industrial, Procurement and RDT&E Activities: User Manual,* Draft Technical Report (CERL).

[9]*Environmental Impact Computer System Attribute Descriptor Package Reference Document,* Technical Report E-86/ADA024303 (CERL, April 1976).

Outline of Report

The guidelines in this manual are designed to produce an EIA/EIS in the format of Table 1. While some of the CEQ guideline points are so general that they can be answered in a few paragraphs, many require use of the tables and figures contained in this manual. Although different projects may vary in amount of detail, the basic EIA/EIS structure remains the same. To guide the user through such a statement, the manual has been organized as follows.

Chapter 2 describes the noise assessment technique by comparing noise contours with land-use maps, and quantifies the noise impact through various single-number descriptors. Chapter 3 describes the development of noise contours and land-use maps. Chapter 4 lists noise mitigation methods, and Chapter 5 summarizes information needed to write the noise analysis for an EIA/EIS according to the eight steps of the CEQ guidelines. The six appendices provide definitional information and information on noise characteristics, and on predicting, measuring, and assessing noise impacts.

Mode of Technology Transfer

It is anticipated that this manual will become a DA Pamphlet issued by the Office of the Chief of Engineers. Additional technology transfer will be through field tests, reports, and the Army Training Literature Program.

Table 1

Summary of Recommended Information to Be Included in EIA/EIS (1)

CEQ Guideline Point	Summary Information to be Supplied in Main Text	Data Sources to be Supplied in Appendix to EIA/EIS*
1	Describe project in terms of major sources, their locations, and their emissions	Fig. 5-9, 11
	Describe existing environment in terms of noise levels and land uses (supply contour maps)	Tables 3, 5, 6, 13
2	Identify possible areas of conflict with current and proposed land uses	Fig. 1, 2, 3, 10
	List planned steps to reduce impact	Table 15
3	Describe and quantify probable noise impact of proposed action	Fig. 2, 10, 12 Tables 3, 6, C2, C3
4	Describe and quantify probable noise impact of alternative actions	Same as in points 1 to 3
5	Quantify impact after mitigation techniques have been applied	Fig. 2, 10, 12 Tables 3, 6, 15, C2, C3
6	Compare positive, short-term effects with detrimental, long-term effects	
	Compare positive long-term effects with detrimental short-term effects	
7	Describe cultural and natural areas that will be permanently impacted by the action	Fig. 2 Tables 3, 6
8	Use DA-PAM-200-1 to satisfy this requirement	

*Data sources should be referenced in main text and then appended. In addition, the appendix should contain a description of all methodologies used to obtain data.

2 NOISE ASSESSMENT GUIDELINES

The intent of a section addressing noise in an EIA or EIS is to describe, as a result of some action, any change in the noise environment and its associated implications on the human environment. Examples of actions are heavy artillery training, use of a new piece of machinery, enlargement or reduction of an existing facility, or an effort to reduce noise at a facility. Any proposed action that will significantly change either the amount of noise generated or the number of people exposed to an existing or new noise requires an EIA/EIS on noise. While the EICS analysis (Figure 1) initially predicts that an impact may exist, this chapter presents guidelines to quantify this impact and to put the result in a format suitable for an EIA/EIS in accordance with Table 1. Five specific steps are detailed:

1. Description of project
2. Preliminary screening
3. Noise environment documentation (NED)
4. Quantification of noise impact
5. Miscellaneous assessments.

Table 2 summarizes the noise descriptions used. Although both noise and vibration are listed, noise will be emphasized in this chapter; vibration will be discussed in Appendix F.

Description of Project

Any complete assessment must describe the proposed activities, and provide details about possible changes (either adverse or beneficial) in the noise environment. This description can be obtained with the following steps:

1. Classify all land within the area of interest into the following use categories:

a. Industrial/commercial

b. Residential

c. Special — schools, hospitals, churches, parks, etc.

2. Plot the land-use data on an appropriately scaled map (details are discussed in Chapter 3). Select acoustic criteria from tables and figures in Appendix C.

3. Generate day-night average sound level (L_{dn}) contours for each source.

4. Overlay a transparent sheet on the land-use map, locate each noise source and plot its contours using the same scale as the land-use map. The contours should begin at the nearest residence, school, hospital, or other noise-sensitive area and extend outward in 5-dB zones until the lower value of the following is achieved: L_{dn} of 55 dB, or value 20 dB lower than initial contour. (The detailed development of noise contours is discussed in Chapter 3.)

5. Combine the noise contours for the different sources to obtain a composite noise contour. Identify impacted areas as illustrated in Figure 2.

Determining Whether a Noise Impact Exists[10]

When the land-use maps and noise contours have been prepared, the flowchart in Figure 3 can be used to find the *initial likelihood of impact*. Figure 3 has

Table 2

Summary of Noise Impact Analysis

Type of Environment	Type of Criteria	Recommended Measure
General Audible Noise	Hearing Loss Potential	L_{dn}
	Health & Welfare Effects on People	L_{dn}
	Environmental Degradation/Effects on Structures and Animals	L_{dn}
High Amplitude Impulsive Noise-Blasts, Artillery	Structural Damage	Peak Pressure/ Peak Acceleration
	Annoyance	C-weighted L_{dn}
Vibration	Structural Damage	Peak Acceleration
	Annoyance and Complaints	RMS Acceleration

two principal branches; each contains a series of exit points where the analysis can stop when it is determined that there is no impact. The goal is to find an exit from each branch as soon as possible and minimize the amount of analysis. Four columns at the right edge of the flowchart indicate the results for each branch and summarize the noise impact analysis for the entire project. The discussion below clarifies the flowchart and the nature of the EIS.

The first branch point occurs in determining the potential noise impact. Branch A should be followed if the project will affect the present noise level. Branch C should be followed if the project will cause vibration in buildings. If the project does not create any impact, the analysis for that branch is complete. The "no=out" route is followed and a check mark is placed in the column labeled "No Environmental Change." Otherwise, the analysis continues.

Even if there is a change expected in the noise environment, the project's location or mode could be such that no noise-sensitive elements are impacted. This accounts for a second set of exit points in branches A and C.

If there is no exposure of wildlife (point A.1), monuments or structures (points A.2 and C.2), de-

[10] *Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 (Committees on Hearing and Bioacoustics, February 1977).

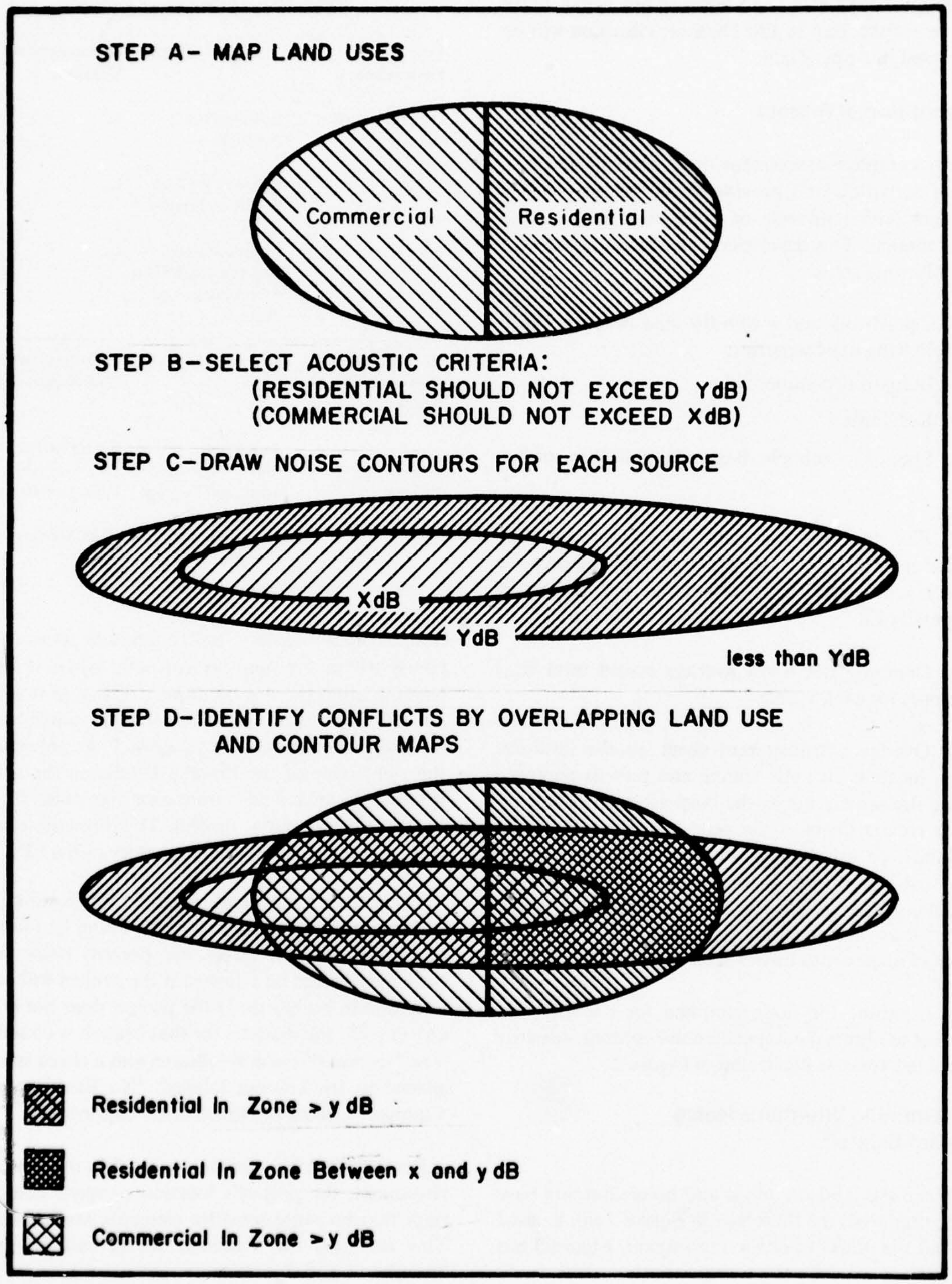


Figure 2. Identifying noise-impacted areas.

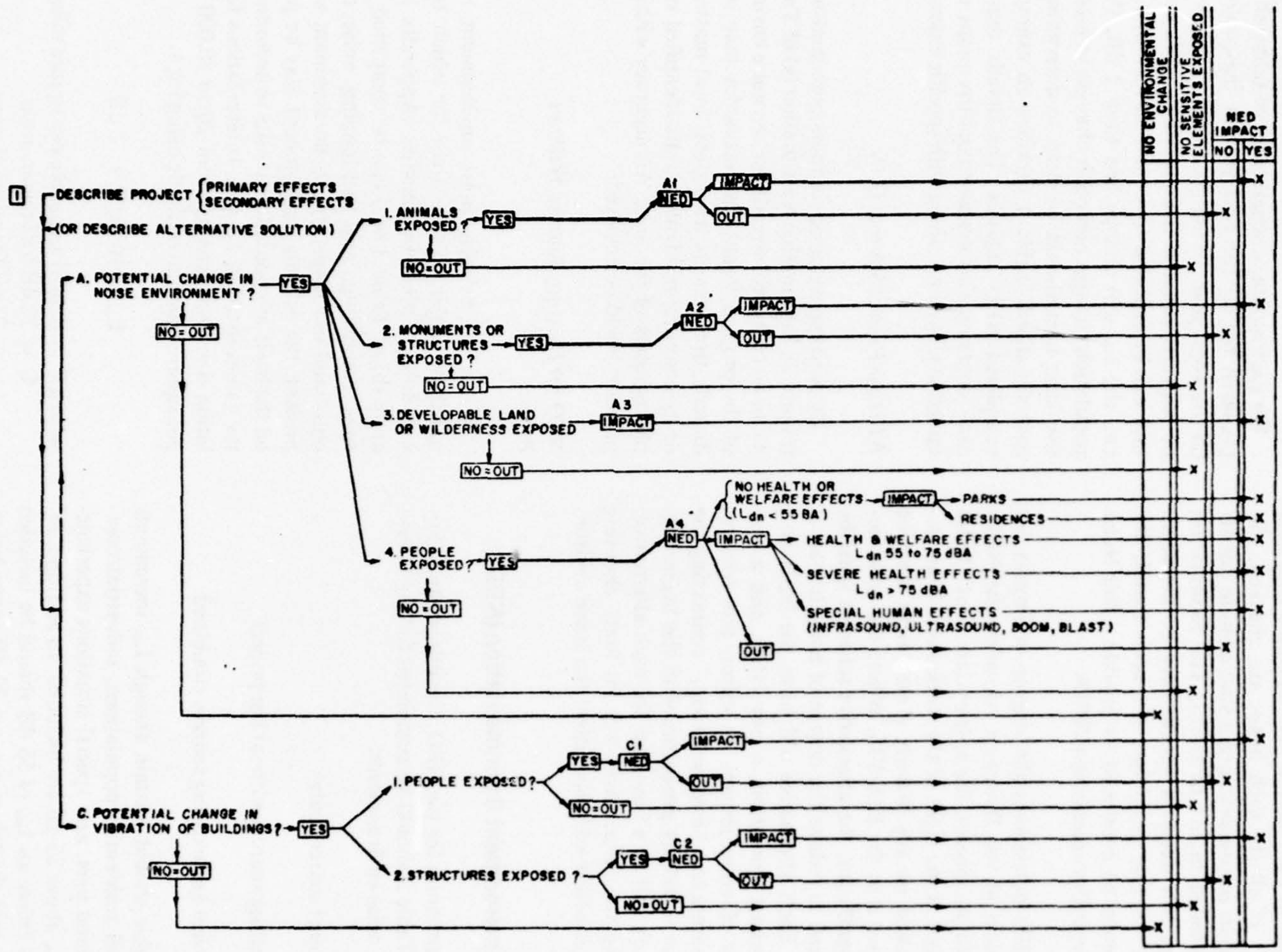


Figure 3. Flowchart and worksheet (from *Guidelines for Preparing Environmental Impact Statements on Noise,* Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

velopable or sensitive landforms (point A.3), or people (points A.4 and C.1), the noise analysis stops at each of these points, and the corresponding boxes are checked in the column, "No Sensitive Elements Exposed." If all six such boxes are checked, *the noise analysis is complete*, and a statement to this effect is included in the EIA/EIS. The information supporting this decision should also be included. Wherever an exit point has not been found, the analysis must be continued to provide a full Noise Environment Documentation (NED).

The NED determines the *degree* of impact for each branch of the flowchart. If, after the NED, there is still no impact, the appropriate "out" boxes are checked at the right of the worksheet. If an impact is found on any branch, a statement must be made about it in the EIA/EIS. Where the noise impact is significant, the alternative schemes must be investigated to reduce the degree of noise impact if possible. Each alternative will form the basis of a new flowchart worksheet, a new NED, and a new statement of noise impact. In effect, this requirement amounts to a "feedback loop," connecting the end of the flowchart procedure with the beginning. Thus, there will be a flowchart for each alternative; comparing the alternatives will facilitate choosing the project which will least affect the noise environment.

Noise Environment Documentation (NED)[11]

As a minimum for the NED, the information outlined in Table 3 should be completed for the following three noise environments:

1. Project sources only
2. Existing sources without the project
3. Project and existing sources combined.

The table should contain enough L_{dn} increments so that all residential populations, industrial/commercial land uses, and special situations experiencing an L_{dn} above 55 dB are included. In addition, increments below an L_{dn} of 55 dB should be included to insure that the tables cover a 20-dB range below the highest L_{dn} to which a residential area is exposed. The increments should not extend below an L_{dn} of 35 dB. Special situations are accounted for in the last column of Table 3.*

For each action, a separate set of tables should be prepared for (1) the first year of the project, and (2) the worst year. In many cases, only one table will be required because the conditions with respect to time can be expected to remain reasonably constant, i.e., the L_{dn} will change less than 2 dB. Proposed population changes and other changes to more sensitive land uses should be used to determine worst-case situations. Table 4 provides an example of a completed NED analysis. The details required to draw contours and prepare land-use maps are contained in Chapter 3, along with specific examples.

NED for Project Sources Only

By overlapping noise contours onto land-use maps (Figure 2), information for situation (a) of Table 3 or 4 can be compiled directly for the noise environment of the project. Population estimates may be taken directly from census tract data, local master plans, or by counting residential units identified on aerial photographs of the area. An accuracy within ± 10 percent should be achieved.

NED for Existing Sources Without Project

When the existing noise environment is dominated by major noise sources for which there are well-defined predictive models (Appendix D), situation (b) of Table 3 or 4 can be completed by plotting, combining, and overlapping noise contours onto land-use maps. When no dominant source is present, the existing environment may be predicted on the basis of population density in accordance with the values listed in Table 5. Interpolations for population densities ranging from 20 to 20,000 persons per square mile can be made using Eq 1.

$$L_{dn} = 10 \log P + C \text{ dB} \qquad \text{[Eq 1]}$$

where P = density in people per square mile
C = 22 dB for civilian areas
27 dB for military areas.

[11]*Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 (Committees on Hearing and Bioacoustics, February 1977).

*The 55-dB level is not to be construed as official Army policy. Because it is only the recommendation of the authors and subject to change, final interpretation should be coordinated with the user's major command and the DA Environmental Office.

Table 3

NED Worksheet

(From *Guidelines for Preparing Environmental Impact Statements on Noise.* Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

Situation	Range in L_{dn} dB	Total Land Area (km²)	Industrial/ Commercial Land Area (km²)	PI Residential Population	Residential Land Area (km²)	Special Situations (See Table 6)
(a)	>85					—
Project	85-80					—
sources	80-75					—
only	75-70					—
	70-65					1,2,3,4
	65-60					5,6,7,8
	60-55					9,10
	Total*					
(b)	>70					—
Existing	70-65					5
sources	65-60					6,7,9
without	60-55					1
project	55-50					3,8,9
	Total*					
(c)	>85					—
Project	85-80					—
and	80-75					—
existing	75-70					—
sources	70-65					1,2,3,4,5
combined	65-60					6,7,8
	60-55					9,10
	Total*					

*Note that the totals for situations a, b, and c are always the same.

NED for Project and Existing Sources Combined

To compile situation (c) of Table 3 or 4, the noise contours from the proposed activity must be combined with noise levels already in the environment as determined in the last section. This noise composite can then be overlapped onto the land-use maps to obtain the desired information.

Special Situation

Table 6 defines the special situations in Table 4. It includes the recommended criterion for each special situation as well as the number of exposed people. These populations may be estimated from industrial, commercial, or public facility employee statistics, and from student enrollments. The effective population (EN) should be used when the population at a location does not remain constant on a weekly or monthly basis (i.e., churches, parks, and stadiums). EN is an average number of people present per hour during the year.

Quantification of Noise Impact[12]

The impact of noise on people is the degree to which it interferes with normal activities (speech, sleep, listening to TV, etc.) and the degree to which it may impair health. Since this impact is a function of both the sound level and population size, one method of quantifying it is to tabulate these two numbers; however, since sound varies with distance from its source, people in different geographic areas will experience different sound levels, thus making comparison of different projects and alternatives difficult.

[12]*Guidelines for Preparing Environmental Impact Statements on Noise,* Draft Report of CHABA Working Group Number 69 (Committees on Hearing and Bioacoustics, February 1977).

Table 4

Sample NED Data Sheet

Situation	Range in L_{dn} dB	Total Land Area (km^2)	Industrial/ Commercial Land Area (km^2)	PI Residential Population	Residential Land Area (km^2)	Special Situations (See Table 6)
(a)						
Project	>85	.8	0	0	0	—
sources	85-80	2.0	1.5	100	.5	—
only	80-75	5.0	4.0	450	1.0	—
	75-70	13.0	8.0	4000	4.50	—
	70-65	36.0	20.0	30000	16.0	1,2,3,4
	65-60	100	69.7	40000	30.0	5,6,7,8
	60-55	289	246.0	10000	33.0	9,10
	Total*	445.8	349.2	84550	85.0	
(b)						
Existing	>70	0	0	0	0	—
sources	70-65	2	2	0	0	5
without	65-60	82	80	10000	2	6,7,9
project	60-55	284.8	262.5	35000	20.8	1
	55-50	77	14.7	39550	62.2	3,8,9
	Total*	445.8	349.2	84550	85.0	
(c)						
Project	>85	.8	0	0	0	—
and	85-80	2.0	1.5	100	.5	—
existing	80-75	5.0	4.0	450	1.0	—
sources	75-70	17.0	10.0	4500	6.5	—
combined	70-65	40.0	22.0	33000	18.0	1,2,3,4,5
	65-60	105	67.7	42000	37.0	6,7,8
	60-55	276	244	4500	22.0	9,10
	Total*	445.8	349.2	84550	85.0	

*Note that the totals for situations a, b, and c are always the same.

The following two assumptions enable a single number to represent the integrated effect of the different sound levels on the total population and thus facilitate the comparison process:

1. Intensity of human response (annoyance, speech interference, and hearing loss) is dependent on average sound level.

2. The impact of high noise levels on a small number of people is equivalent to the impact of lower noise levels on a larger number of people.

Thus, different numerical degrees of impact can be ascribed to different segments of the population, depending on the average sound level of their exposure. Their product, defined as "Fractional Impact" can be summed over the entire population to provide the single number descriptor:

$$EP = \sum_{i=1}^{n} P_i W_i \qquad \text{[Eq 2]}$$

where EP = equivalent population response such as LWP & PHL [these will be detailed in the next section]

P_i = population in i^{th} L_{dn} increment [L_{dni}]

n = number of L_{dn} increments

W_i = response criterion for L_{dni}.

The noise measure no longer retains its identity on a decibel scale but becomes a population-weighted measure of the severity of an area of impact. In addition, by dividing EP by the total population, an average response ($\overline{EP}$) to the action can be determined:

$$\overline{EP} = EP/\text{Total Population} \qquad \text{[Eq 3]}$$

The use of these single number descriptors *is the key to quantitative impact statements*. In addition to

Table 5

L_{dn} Levels as a Function of Population Density

(From *Population Distribution of the United States as a Function of Outdoor Noise Level*, EPA 550/9-74-009 [U.S. Environmental Protection Agency, June 1974] and field data obtained at CERL.)

Description	Population Density (people/sq mi)	L_{dn} in dB Civilian Areas	Military* Areas
Rural (undeveloped)	20 and under	35	
Rural (partially developed)	60	40	
Quiet suburban	200	45	50
Normal suburban	600	50	55
Urban	2000	55	60
Noisy urban	6000	60	65
Very noisy urban	20000 and over	65	70

*Direct measurements indicate that military areas are inherently 5 dB louder than comparable civilian areas. This is perhaps caused by the age and activities of the inhabitants. This difference has been accounted for in this table.

supplementing the verbal description, these descriptors can be powerful decision-making tools. For example, if action A impacts 100 equivalent people and its alternative B impacts 200 people, then from a noise standpoint, action A is 50 percent less intrusive and hence an optimum choice.

Specific examples of these descriptors are detailed below. In each case, data from the NED analysis in Table 4 is used in the computations.

Sound Level Weighted Population (LWP) is a single-number representation of the noise impact based on the concept that some annoyance begins at 35 dB L_{dn} values, with increasing reaction as the level intensifies. The equation for calculating LWP is:

$$LWP = \sum_{i=0}^{n} P_i W_i \qquad \text{[Eq 4]}$$

where n = the number of L_{dn} increments

P_i = the population within the i^{th} L_{dn} increment

W_i = response criterion for L_{dn_i}.

The average annoyance per person, $\overline{LWP}$, is defined by:

$$\overline{LWP} = LWP/\text{Total Population} \qquad \text{[Eq 5]}$$

Table 6

Special Situation Data Sheet

(From *Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

Type of Noise Sensitive Facility	Effective Population* Day	Effective Population* Night	Area (km²)	Criteria Level**
1. Park with wildlife	11	—	0.5	60
2. Hospital	200	200	—	55
3. School	500	150	—	60
4. Outdoor stadium	542	—		70
5. Hotel	200	200	—	60
6. Schools	4000	1200	—	60
7. School	500	150	—	60
8. Stadium	1286	—	—	70
9. Nursing home	200	200	—	55
10. Park with picnic grounds	14	—	0.3	60

$$\text{*Effective Population (EN)} = \frac{1}{n} \sum_{i=1}^{n} P_i$$

where n = number of hours in a year

P_i = number of people using facility during the i^{th} hour.

**Criteria levels assume average acoustical insulation of building. Adjustments can be made for inferior or superior insulation.

Table 7 gives values of W_i, numerically derived from social survey data relating fraction of sampled populations expressing a high degree of annoyance at various L_{dn} values.

Example

Quantify the impact for the NED analysis in Table 4, using LWP. Compare the following situations:

1. Existing sources without project.

2. Project and existing sources combined.

Step 1. Compute LWP and $\overline{LWP}$ for situation 1 using the following format.

L_{dn} Range	Mid Point	P_i Population	W_i Weighting	$(P_i) \cdot (W_i)$
>70	—	0	—	0
65-70	67.5	0	0.538	0
60-65	62.5	10,000	0.324	3,240
55-60	57.5	35,000	0.181	6,335
50-55	52.5	39,550	0.094	3,575.32
		Total Population: 84,550		ΣP_iW_i 13,150

$$LWP = \sum_{i=1}^{N} P_iW_i = 13{,}150 \qquad \text{[Eq 6]}$$

$$\overline{LWP} = 13{,}150/84{,}550 = .155 \qquad \text{[Eq 7]}$$

Step 2. Compute LWP and $\overline{LWP}$ for situation 2 using the format below.

L_{dn} Range	Mid Point	P_i Population	W_i Weighting	$(P_i) \cdot (W_i)$
>85	—	0	2.305	00
80-85	82.5	100	1.695	169
75-80	77.5	450	1.203	541
70-75	72.5	4,500	0.832	3,744
65-70	67.5	33,000	0.538	17,754
60-65	62.5	42,000	0.324	13,608
55-60	57.5	4,500	0.181	814
		Total Population: 84,550		ΣP_iW_i 36,631

$$LWP = \sum_{i=1}^{N} P_iW_i = 36631 \qquad \text{[Eq 6]}$$

$$\overline{LWP} = 36631/84550 = .433 \qquad \text{[Eq 7]}$$

Step 3. Compare results. For the 84,550 people affected by the action, the number of equivalent annoyed people increases from 13,150 to 36,631, or 277 percent, as a result of the action. The average annoyance per person ($\overline{LWP}$) increases from 15.5 percent to 43.3 percent.

Population Weighted Loss of Hearing (PHL) is a single number representing the potential loss of hearing expected from a population experiencing L_{dn} levels in excess of 75 dB. It is based on the concept that hearing loss begins at L_{dn} levels of 75 dB and increases with noise intensity. This quantity is computed as

$$PHL = \sum_{j=0}^{N} P_jH_j/P_T \quad \text{dB/person} \qquad \text{[Eq 8]}$$

where N = number of L_{dn} increments

P_j = population within the j^{th} L_{dn} increment

H_j = hearing loss weighting function for L_{dn_j} (Table 8)

P_T = total population experiencing L_{dn} levels in excess of 75 dB.

Example

Using PHL and the format below, quantify the impact from the NED analysis in Table 4. Only consider the project and existing sources combined.

L_{dn}*	P_j Population	H_j Weighting	$P_j \cdot H_j$
>83	0	—	—
81-82.9	50	1.225	61.25
79-80.9	200	0.625	125.0
77-78.9	200	0.225	45.0
75-76.9	100	0.025	2.5
Total	P_T: 550	—	ΣP_jH_j: 233.75

*For purposes of the example, 2 dB L_{dn} increments were formulated from Table 4.

Table 7

W_i Values Relating Annoyance to L_{dn} Values

(From *Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

L_{dn}	W_i
35	0.006
37.5	0.010
40	0.013
42.5	0.021
45	0.029
47.5	0.045
50	0.061
52.5	0.093
55	0.124
57.5	0.180
60	0.235
62.5	0.324
65	0.412
67.5	0.538
70	0.664
72.5	0.832
75	1.000
77.5	1.214
80	1.428
82.5	1.697
85	1.966
87.5	2.307
90	2.647

Table 8

Values of H_j Versus L_{dn} Level

(From *Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

L_{dn} in dB	H_j
75 and below	0
76	0.025
77	0.100
78	0.225
79	0.400
80	0.625
81	0.900
82	1.225
83	1.600
84	2.025
85	2.500
90	5.625
95	10.0

$$PHL = \sum_{j=1}^{n} P_j H_j / P_T \qquad \text{[Eq 8]}$$

$$PHL = 233.75/550 = 0.4 \text{ dB for 550 people}$$

For the 550 people who experience L_{dn} levels above 75 dB, the average degradation in hearing can be expected to be 0.42 dB.

Miscellaneous Assessments

The procedures discussed in the previous section will apply to most general assessments; however, certain situations require variations.

Vibration Evaluation

See Appendix F.

Temporary Noise Environments[13]

For situations requiring a detailed analysis of a temporary noise environment, Figure 3 is used to screen the process. Then, if required, a detailed assessment is made by computing the LWP and PHL for three situations:

1. The temporary noise environment as if it were permanent.

2. The temporary noise environment in terms of its contribution to the annual average L_{dn} level using:

$$L_{dny} = 100 \log_{10} \left[\frac{a}{12}(10)^{La/10} + \frac{b}{12}(10)^{Lb/10}\right] \qquad \text{[Eq 9]}$$

where a = number of months of temporary operation
b = 12 − a
L_{dny} = annual average day-night sound level
La = L_{dn} value during temporary operation
Lb = L_{dn} value after operation is completed.

3. The environment after the activity is completed.

Example

A population of 1000 experiences a temporary L_{dn} level of 70 dB for 9 months due to a construction project, after which the average L_{dn} drops to 60 dB on a long-term basis. Describe the noise impact.

Step 1. Compute LWP and PHL for the 9-month construction.

$LWP = \Sigma P_i W_i$

$W_i = .664$ for 70 L_{dn} (Table 7)

$LWP = 1000 \times .664 = 664$

$\overline{LWP} = LWP/1000 = .664$

PHL = 0, so there is no need to consider it again.

Step 2. Compute LWP for a yearly period using Eq 9 to obtain the annual average L_{dn} level.

$$L_{dny} = 10 \log_{10} \left[\frac{9}{12}(10)^{70/10} + \frac{3}{12}(10)^{60/10}\right]$$

$$= 68.9 \text{ dB} \qquad \text{[Eq 9]}$$

$LWP = \Sigma P_i W_i$

$W_i = .600$ for L_{dn} value of 68.9 (Table 7)

$LWP = 1000 \times .600 = 600$

$\overline{LWP} = LWP/1000 = .600$

Step 3. Compute LWP after construction is complete.

[13] *Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 (Committees on Hearing and Bioacoustics, February 1977).

$LWP = \Sigma P_i W_i$

$W_i = .235$ for L_{dn} value of 60 (Table 7)

$LWP = 1000 \times .235 = 235$

$\overline{LWP} = LWP/1000 = .235$

Step 4. Compare results. Of the 1000 people affected during construction, 664 are equivalently annoyed, with the average person 66.4 percent annoyed by the noise. If the effects are considered over the entire year, the number of equivalently annoyed people drops to 600, with the average person 60 percent annoyed. After the operation is completed, there will be 235 equivalently annoyed people due to the other noise sources in the area. The average person will remain 24 percent annoyed. There is no danger of hearing loss since PHL = 0. Nonetheless, the construction phase will create a significant, although temporary, increase in the noise impact.

Land-Use Planning

To determine the probable impact of existing noise environment on proposed civilian and military activities, the following steps can be applied.

1. Map out proposed activity on land-use map.

2. Select criteria from Table C1 of Appendix C.

3. Use the procedures on page 20 (NED for Existing Sources Without Project) to determine existing noise levels and map them on a transparent overlay.

4. Overlap transparent overlay on land-use map to determine possible conflict (i.e., if existing levels are incompatible with proposed activity).

5. Use procedures in Chapter 4 to mitigate the impact.

Population Movement

Projects which relocate large numbers of people are also subject to an EIA/EIS if the noise environments are changed; i.e., if the people are moved into an area with a higher or lower noise environment than their present location. This analysis requires completion of the NED in Table 3 both before and after the relocation. It should be noted that only the Pi column is of interest here, since land areas will not necessarily be the same. Calculations of the LWP and PHL remain the same.

Adding New Source to High Noise Area

When a high noise activity is put into an area that already has high noise levels, there will be little increase in the LWP and PHL indicators due to the logarithmic addition of sound levels. For example, if an activity with a project L_{dn} of 65 is put into an area with an existing L_{dn} of 70, the resultant L_{dn} is $65 \oplus 70 = 71$ (see Appendix B for discussion on decibel addition). While this 1-dB increase does not appear significant, this circumstance should not mask the impact of the new activity. In this situation, the NED evaluation in Table 3 for *project sources only* should be used to quantify the impact. This should also be accompanied by a statement that the activity will be located in a high noise area so that the actual increase in the noise environment will not be noticed.

Environmental Legislation

Step 2 of the CEQ guidelines requires information about the relationship of each activity of land-use plans, policies, and controls for the affected area. An evaluation of Army activities in relation to applicable Federal, state, and local environmental noise legislation is needed to satisfy this requirement. This consists of the following steps:

1. Inventory and review all applicable noise legislation. The Computer-Aided Environmental Legislative Data System (CELDS), developed by CERL, can provide summaries of pertinent Federal and state legislation.[14]

2. Examine the structure of the administering agency and the enforcement procedure, and the effectiveness of the enforcement program. This examination should include methods of enforcement (voluntary or mandatory) and specific penalties. Since few guidelines can be expected from unenforced legislation or unbudgeted programs, caution must be exercised before undertaking a compliance program.

3. Examine each law in terms of the following questions.

[14] R. L. Welsh, *User Manual for the Computer-Aided Environmental Legislative Data System*, Technical Report E-78/ADA 019018 (CERL, 1975).

a. Do variances and exemptions exclude Army activities?

b. What noise measures are used in establishing compliance?

c. Are regulations based on emission levels of individual sources or on maximum levels across property lines?

d. What measurement procedures are required to determine compliance?

4. Determine compliance. Emission levels of individual sources can be determined by direct measurement (Appendix E), while levels across property lines can be determined by either prediction (Appendix D) or measurement. When using prediction methods, contours should be calculated in the same units as the legislation and then overlaid on land-use maps. Violations can be determined by scanning the overlays. Chapter 4 discusses mitigation techniques for violations.

Baseline Assessment

To obtain an acoustic baseline of Army activities, Table 3 should be compiled for the existing sources without the project.

Conclusion

The procedures, graphs, and tables developed in this section can be used directly in the EIA/EIS as indicated in Table 9. Their foundation, however, is based on the development of land-use maps and noise contours, which are detailed in the next chapter, along with specific examples of the NED analysis.

Table 9

Summary of Recommended Information to Be Included in EIA/EIS (2)

(Figures and tables already addressed in text are in bold type.)

CEQ Guideline Point	Summary Information to be Supplied in Main Text	Data Sources to be Supplied In Appendix to EIA/EIS*
1	Describe project in terms of major sources, their location and their emissions	Fig. 5-9, 11
	Describe existing environment in terms of noise levels and land uses (supply contour maps)	Tables **3, 5, 6,** 10
2	Identify possible areas of conflict with current and proposed land uses	Fig. **1, 2, 3,**10
	List planned steps to reduce impact	Table 11
3	Describe and quantify probable noise impact of proposed action	Fig. **2,** 10, 12 Tables **3, 6,** C2, C3
4	Describe and quantify probable noise impact of alternative actions	Same as in points 1 to 3
5	Quantify impact after mitigation techniques have been applied	Fig. **2,** 10, 12 Tables **2, 5,** 11, C2, C3
6	Compare positive, short-term effects with detrimental, long-term effects	
	Compare positive long-term effects with detrimental short-term effects	
7	Describe cultural and natural areas that will be permanently impacted by the action	Fig. **2** Tables **3, 6**
8	Use DA-PAM-200-1 to satisfy this requirement	

*Data sources should be referenced in main text and then appended. In addition, appendix should contain description of all methodologies used to obtain data.

3 THE DEVELOPMENT OF NOISE CONTOURS AND LAND-USE MAPS

The most fundamental step in assessing noise impact is the development of noise contours. Noise contours indicate lines of constant noise level in the same manner that isobars indicate lines of constant air pressure on a weather map. They are first used to determine the extent of the impact in the initial screening (Figure 4) and later to quantify the impact in the NED (Table 3). An additional fundamental step is the development of land-use maps and their relation to the contours. Both are detailed in this chapter.

Basic Concepts of Contouring

Army activities can be characterized by the following groups of noise sources:

1. Impulse noise (blasts, artillery, pistol ranges)

2. Airport operations (fixed-wing, rotary-wing, ground run-ups)

3. Transportation (private vehicles, combat vehicles, railroads)

4. Construction

5. Fixed sources (industrial operations, engine testing, miscellaneous).

These sources can be classified as either intermittent or continuous. Intermittent sources are single, discrete events where the noise level rises with time, reaches a maximum value, and then decays to the background level. The noise exposure from this type of source is assessed in terms of the sound level attained and the number of such events which occur throughout the day.

In contrast, continuous sources are those whose sound level rises to a particular value and remains there for an extended period of time. These sources are assessed in terms of the maximum level and duration of such occurrences. The concepts are expressed explicitly in the following two sets of equations in which equivalent noise level (L_{eq}) and day-night average noise level (L_{dn}) values are calculated based on the emitted noise level.

Intermittent Source

$$L_{eq} = SEL + 10 \log_{10} N \qquad \text{[Eq 10]}$$

$$L_{dn} = SEL + 10 \log_{10}(N_d + 10N_n) - 49.4 \qquad \text{[Eq 11]}$$

where L_{dn} = day-night average noise level

L_{eq} = equivalent noise level (1 hour)

SEL = maximum sound exposure level occurring for a single event*

N = number of individual events occurring within a 1-hour period

N_d = number of daytime operations (0700-2200)

N_n = number of nighttime operations (2200-0700)

*SEL and AL values for various noise sources are provided in Appendix D.

Continuous Source

$$L_{eq} = AL + 10 \log_{10}(D) - 35.6 \qquad \text{[Eq 12]}$$

$$L_{eq} = AL \qquad \text{[Eq 13]}$$

where source operates throughout period of interest.

$$L_{dn} = AL + 10 \log_{10}(D_d + 10D_n) - 49.4 \qquad \text{[Eq 14]}$$

where AL = maximum A-weighted sound level of the event*

D = event duration in seconds within a 1-hour period

D_d = event duration in seconds during daytime (0700-2200)

D_n = event duration in seconds during nighttime (2200-0700).

Although the equations to develop L_{dn} and L_{eq} differ somewhat, the contouring procedure for both intermittent and continuous events at a single location is identical, consisting of the following steps.

Step 1. Determine the SEL (for intermittent sources) or AL (for continuous sources) at the location of interest (X) for each type of operation.

Step 2. Tabulate the number of discrete events (for intermittent sources) or duration (for continuous sources) for each type of operation. The following data can be used:

a. Average daily units—divide total number/duration of operations in a typical month by 30.

b. Average hourly unit—divide total number/duration of operations in an average day by 24.

c. Worst case—complete maximum possible number/duration of operations that can occur during a day/hour.

Step 3. Determine the L_{dn} or L_{eq} value for each type of operation using Eqs 10 through 14.

Step 4. If more than one type of operation occurs at the same location, determine the total L_{dn} or L_{eq} value for all operations by using Table 10 to add logarithmically the individual L_{dn} or L_{eq} values.

*SEL and AL values for various noise sources are provided in Appendix D.

Table 10

Decibel Addition*

When Two dB Values Differ by	Add to the Higher Value
0 or 1 dB	3
2 or 3 dB	2
4 to 9 dB	1
10 or more dB	0

*Decibel addition will be noted by the term $\oplus$. Thus, while $90 + 90 = 180$, $90 \oplus 90 = 93$ according to this table.

Step 5. Make *adjustments* for other noise-sensitive areas (Y) using Eq 15.

$$ADJ = k\log_{10}Y/X \qquad [Eq\ 15]$$

where X = initial distance from source
Y = other distances from source
k = constant dependent on type of source (see Appendix D).

Step 6. Draw equal noise contours around source. The procedure is illustrated in the following two examples. The first shows how to draw contours for a single source; the second shows how to add levels for several different sources operating at the same location.

Example

A single source emits a continuous noise level of 70 dBA at 50 ft (15 m) for 10 hours during the day. Plot the contours for the following distances: 25 ft, 50 ft, 100 ft, 200 ft (7.5 m, 15 m, 30 m, 60 m).

Step 1. Determine AL at the location of interest.
AL = 70 dBA at 50 ft (15 m)

Step 2. Determine the duration for each type of operation.

D_d = 10 hours (36,000 sec)

$D_n = 0$

Step 3. Calculate L_{dn} from Eq 14.

$$L_{dn} = AL + 10\log_{10}(D_d + 10D_n) - 49.4$$

$$= 70 + 10\log_{10}(36000 + 10(0)) - 49.4$$

$$= 65.2\ dB$$

Step 4. Determine total L_{dn} value for all operations; since there is only one operation.

$L_{dn} = 65.2$

Step 5. Adjust L_{dn} level to each distance using Eq 15 and the format below.

$$ADJ = 20\log_{10} Y/X \qquad [Eq\ 15]$$

Distance (Y)	25 ft (7.5 m)	50 ft (15 m)	100 ft (30 m)	200 ft (60 m)
L_{dn} at 50 ft (15 m)	65.2	65.2	65.2	65.2
ADJ	+6	0	−6	−12
L_{dn} at Y	71.2	65.2	59.2	53.2

Step 6. Draw contours around source (Figure 4).

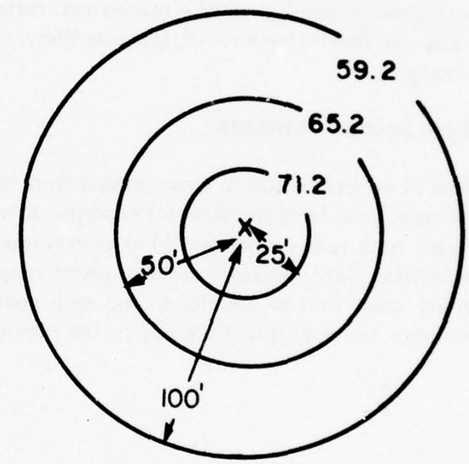


Figure 4. L_{dn} contours (concentric circles) for a single source.

Example

Determine the total L_{dn} at a site exposed to the following operations:

Event	SEL	No. of Operations Daytime	Nighttime	Total
A	80	27	3	30
B	85	45	5	50
C	90	18	2	20

Steps 1 and 2. SEL levels and number of events can be taken directly from information above.

Step 3. Determine L_{dn} for each operation using Eq 11.

$$L_{dn} = SEL + \log_{10}(N_d + 10N_n) - 49.4 \quad \text{[Eq 11]}$$

For Event A—

$L_{dn} = 80 + 10 \log(27 + (10 \times 3)) - 49.4 = 48.0$

For Event B—

$L_{dn} = 85 + 10 \log(45 + (10 \times 5)) - 49.4 = 55.5$

For Event C—

$L_{dn} = 90 + 10 \log(18 + (10 \times 2)) - 49.4 = 56.5$

Step 4. From Table 10, calculate total L_{dn}

Total $L_{dn} = 48.0 \oplus 55.5 \oplus 56.5 = 59.5$ dB

Appendix D contains models to generate contours for more complicated sources, which include railroads, highways, combat vehicle maneuvers, rotary-wing aircraft, fixed-wing aircraft, blast/artillery, and pistol ranges.

Multiple Source Contours

Often in an EIA/EIS, the noise impact from several sources must be quantified (for example, a base may have both rotary-wing and blast operations or an industrial plant located next to a pistol range). Contours must first be developed for each source using either the concepts discussed in the previous section or the models in Appendix D. Then, the individual contours are combined into a composite using the steps outlined below. Because of their complexity, these steps are illustrated by examples.

Step 1. Draw contours for each source in 5-dB increments, extending them to 5 dB lower than the level of interest; i.e., if the level of interest is 65, extend contours to 60. Mark overlapping contour intersections (see Figure 5).

Step 2. At each intersection, add the levels logarithmically according to Table 10 (Figure 6).

Step 3. Put the L_{dn} levels into the categories shown in Table 11 (Figure 7).

Table 11

Categorizing Noise Levels

Group	L_{dn} **Range**
A	75-79.9
B	70-74.9
C	65-69.9
D	60-64.9
E	55-59.9
F	50-54.9
G	45-49.9
H	40-44.9

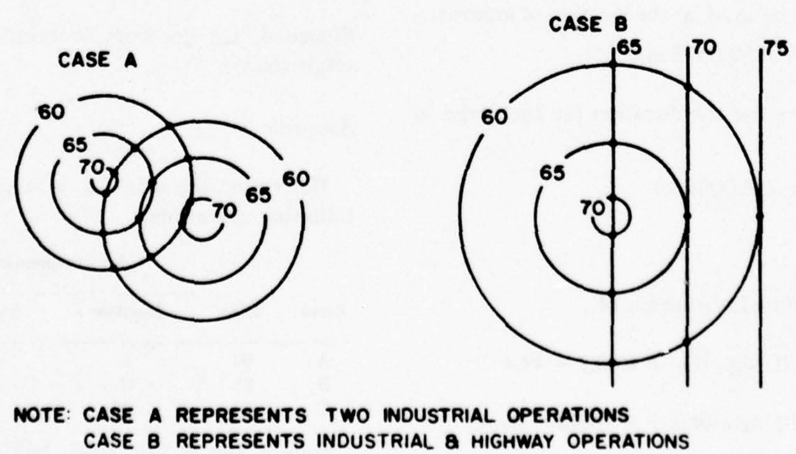


Figure 5. Contours for individual sources.

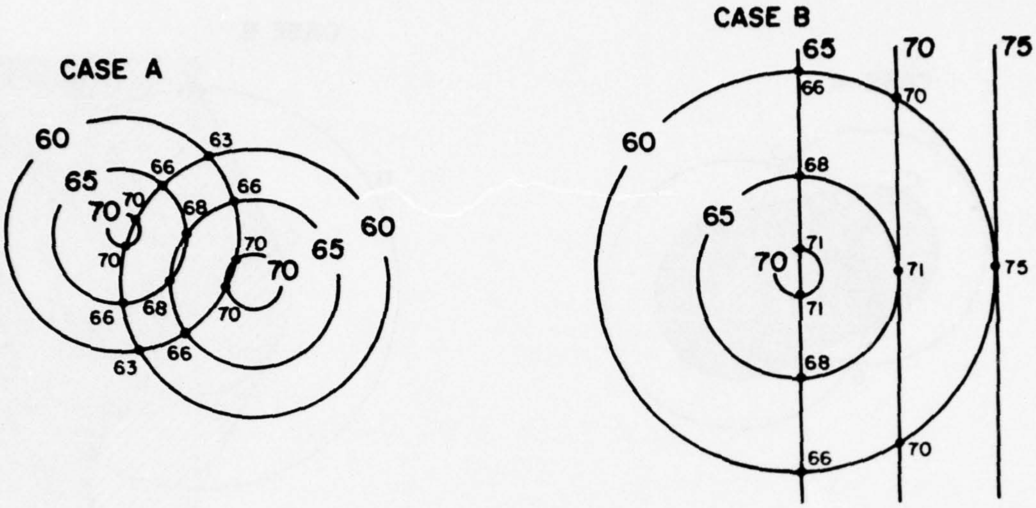


Figure 6. Addition of intersecting contours.

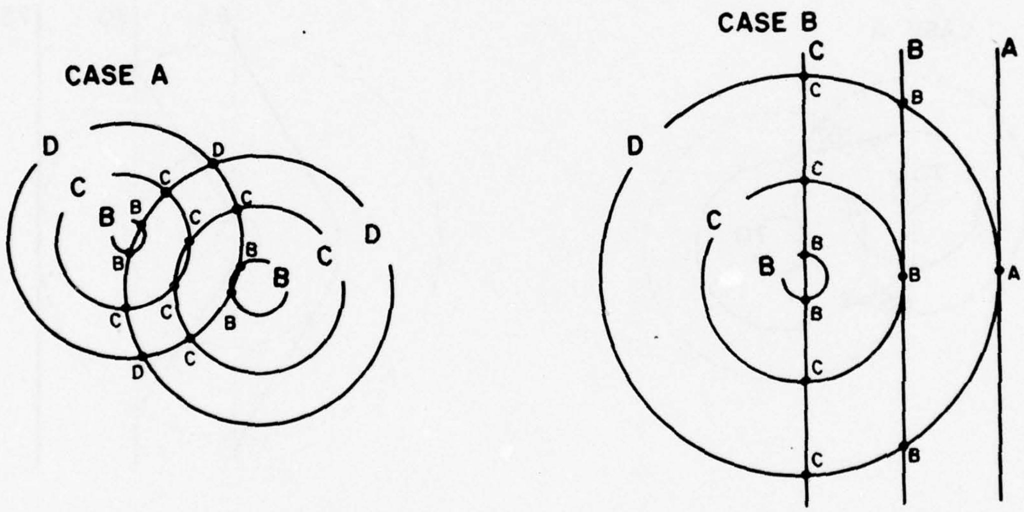


Figure 7. Categorizing contour levels.

Step 4. Starting with Category A, connect all the contours and points labeled "A." Do not cross more than one contour line with a different label. Shade the area. Continue with Categories B, C, etc. (Figure 8).

Step 5. Use Table 11 to put L_{dn} levels on each zone. The composite contour (Figure 9) can now be used with the land-use maps to quantify the impact.

Dependence of Land-Use Maps on Noise Contours

Preparing land-use maps is a fairly straightforward procedure where various land uses and noise-sensitive areas are marked off on aerial photographs, installation specialty maps, etc. (Table 12). However, the detail involved in this process is very dependent on the size of the noise contour influencing the area.

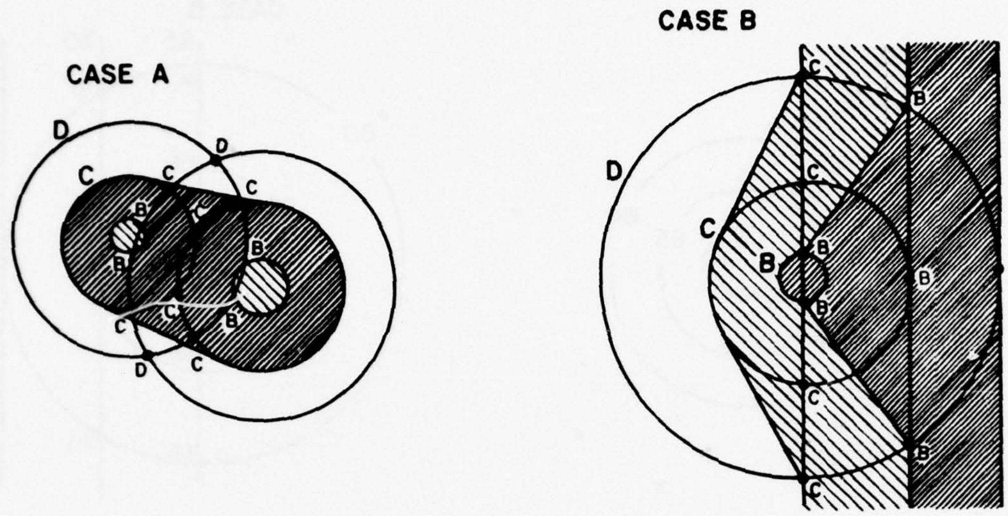
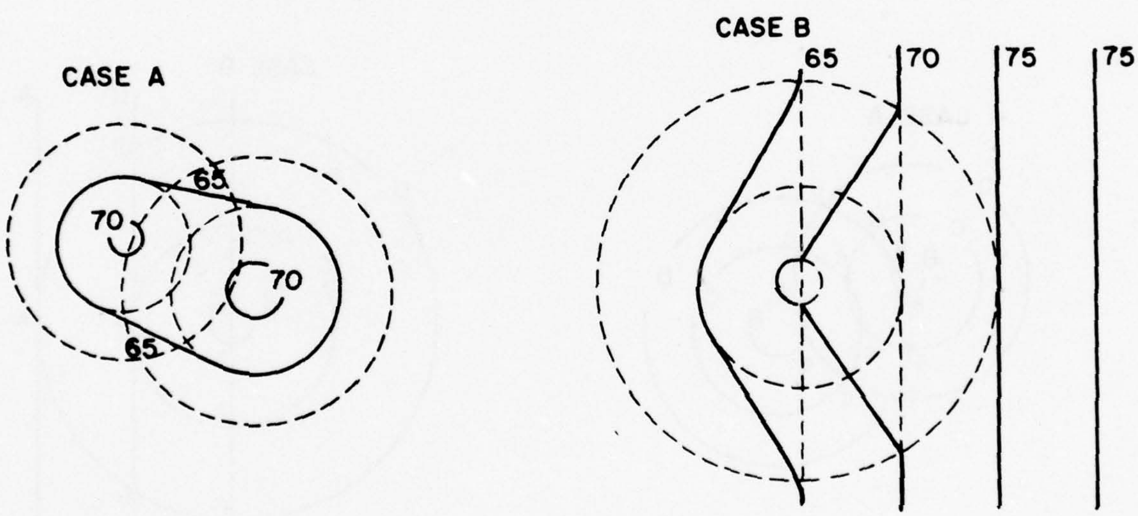


Figure 8. Combining equal noise levels.



—— COMPOSITE CONTOUR
- - - - SEPARATE CONTOUR OF INDIVIDUAL SOURCES

Figure 9. Composite contours.

For example, if a single source produces intrusive noise levels to a distance of a few hundred meters, impacts on all the land uses within the area can be detailed fairly easily. Every school, church, house, commercial establishment, park, etc., can then be tabulated and analyzed as in Table 4. On the other hand, if that source impacts an area of several thousand square kilometers, detailing all the sensitive land uses becomes impractical, because the time required is prohibitive. Between these two extremes is a situation which requires a compromised degree of detail. Table 13 summarizes this relationship. The area encompassed by the contours determines the type of analysis and degree of detail. The grid system

Table 12

Map Availability (Sources and Scale)

Source	Description	Availability	Scale (in thousands)	Type of Analysis (see Table 13)
United States Geological Survey (USGS)	Topographic Information	Entire U.S. Limited Limited	1:250* 1:62.5 1:24.5	III II, III II, III
Defense Mapping Agency	Most installation maps, primarily specialty maps			II, III
Installations (Director of Plans and Training)	Specialty maps—Outlines training areas/entire installation (usually using metric grid coordinates)	Most major installations	1:50 1:25	II, III II, III
U.S. Dept. of Agriculture (USDA) Agriculture-Soil Conservation Service (ASCS)	Aerial Photographs	Over 70% of U.S.	1:20 std. (or any scale desired)	II
Installation (Master Planner)	Cantonment Area Maps (1200, 800, 400 foot maps)	All installations	1:14.4 1:9.6 1:4.8	II I, II I
U.S. Census	Census tract maps	Approx. one-half of U.S.		II
U.S. Dept. of Interior (Natl. Cartographic Information Center [NCIC], U.S. Geological Survey, 507 National Center, Reston, VA 22092)	Foremost experts on map availability, scale, and source, except for USDA aerial photographs	Depending on scale and original source		All

*1:250 = 1 in. on map is equivalent to 250,000 in. on the ground.

Table 13

Noise Contour Area Vs. Land-Use Detail

Type of Analysis*	Degree of Detail	Area of Contours	Size of Grid	Sources
I	Most	less than 10^6 sq ft [93025 m^2]	200 × 200 ft (60 × 60 m)	Industrial
II	Some	10^6 sq ft to 5 sq mi [93025 m^2 to 12.8 km^2]	250 m × 250 m (750 ft × 750 ft)	Pistol range, highway, construction
III	Least	more than 5 sq mi [12.8 km^2]	500 m × 500 m (1500 ft × 1500 ft)	Aircraft, blast

*See corresponding column in Table 12 to determine recommended map.

is described via a series of examples in the next section. The sources listed in the last column of Table 13 are those most likely to produce contours having the prescribed areas.

Examples of NED Analyses

This section provides a series of examples which describe the three types of analysis used in Table 13. Each example shows how to produce the noise contours and land-use maps requisite to the NED in Table 4 for the following situations:

1. Project sources only (Figure 10)

2. Existing sources without project (Figure 11)

3. Project and existing sources combined (Figure 12)

Each example illustrates how the general approach (prediction techniques, land-use preparation, etc.) varies with the type of analysis. Unless otherwise stated, there are no major noise sources in the area other than arterial roadways. The level of interest is the L_{dn} 60 contour. The steps below can be used as guidelines for all assessments.

Type I Analysis (Power Plant)

A new power plant has been put into operation.

Project Sources Only (Figure 10)

1. Use procedures in Appendix E to measure noise levels (AL).

2. Obtain operational information and calculate L_{dn} using Eq 14.

$$L_{dn} = AL + 10 \log_{10}(D_d + 10D_n) - 49.4 \quad \text{[Eq 14]}$$

3. Using Eq 15 to calculate the distance to the L_{dn} 60 contour.

$$ADJ = 20 \log_{10} Y/X \quad \text{[Eq 15]}$$

Plot this contour on a transparent sheet. The area encompassed determines the type of analysis (for this example, assume that the area is less than 10^6 sq ft [92 903 m^2]; thus, a Type 1 analysis is applied).

4. Use Eq 15 to adjust for different levels and plot higher contours in 5-dB increments.

5. Overlay the transparent sheet on the aerial photograph, USGS map, or base contonment area map so that the contours align with the noise source location. The scales of the two maps must be identical.

6. Prepare the land-use map by labeling all land-use areas within the L_{dn} 60 contour, including schools, hospitals, parks, and individual houses, as well as commercial establishments and industrial areas.

7. Data for Table 3 can be compiled directly with this information.

Existing Sources Without Project (Figure 11)

8. Plot grid system 200 × 200 ft (60 × 60 m) on a transparent sheet.

9. Overlay the grid system on land-use maps, and locate the center of each grid. The scales of the two maps must be identical.

10. Perform a site noise survey at this location by measuring the L_{dn} using the procedures in Appendix E. Plot this number in the respective grid on the transparent sheet.

11. Data for Table 3 can be compiled directly from this information.

Project and Existing Sources Combined (Figure 12)

12. Overlay the transparent sheet containing the project's noise contours on a sheet containing the grid system.

13. Where contours intersect the grid, add two levels logarithmically using Table 10.

14. Overlay the new sheet on the land-use map. The scales of the two maps must be identical.

15. Data for Table 3 can be compiled directly from this information.

Type II Analysis (Pistol Range)

A new pistol range is being planned for a facility.

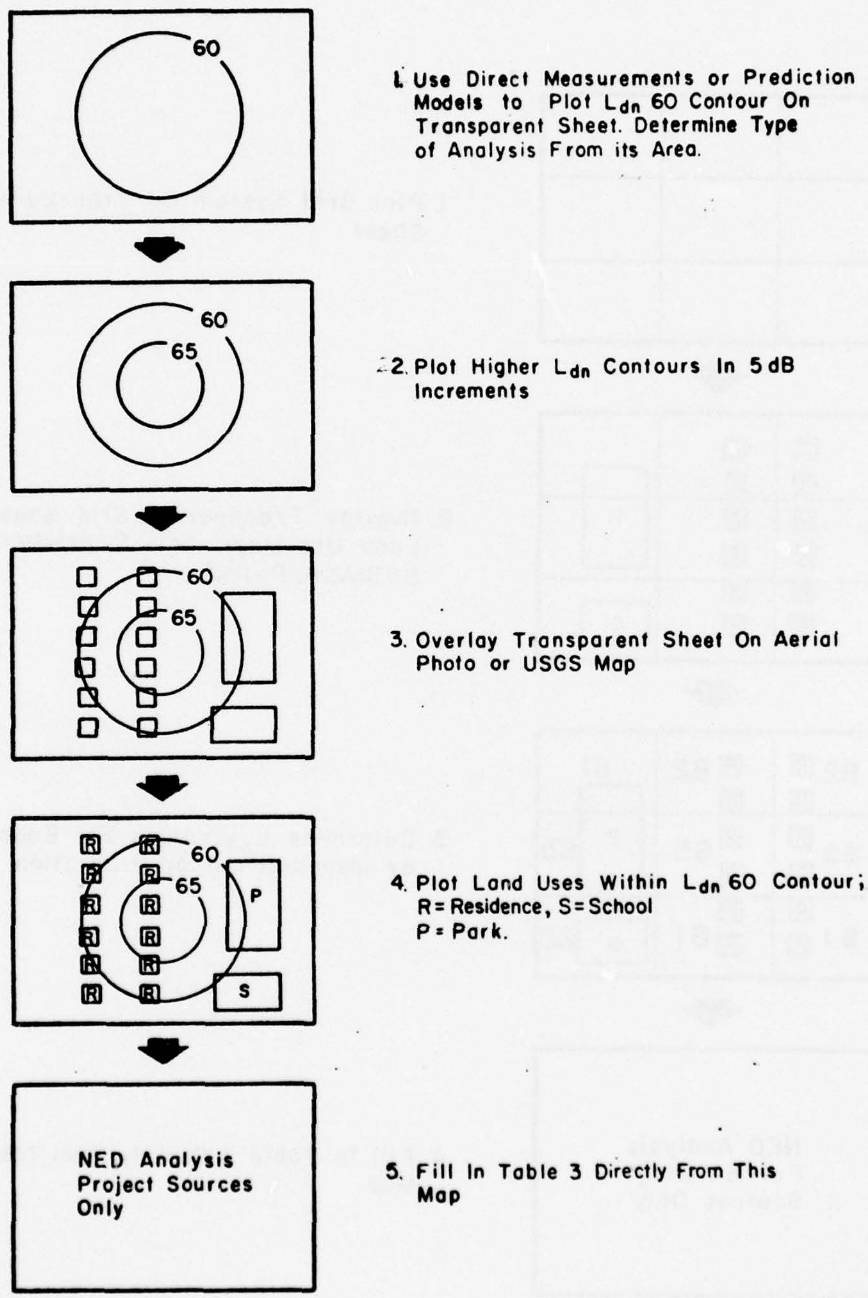


Figure 10. NED analysis for project sources only.

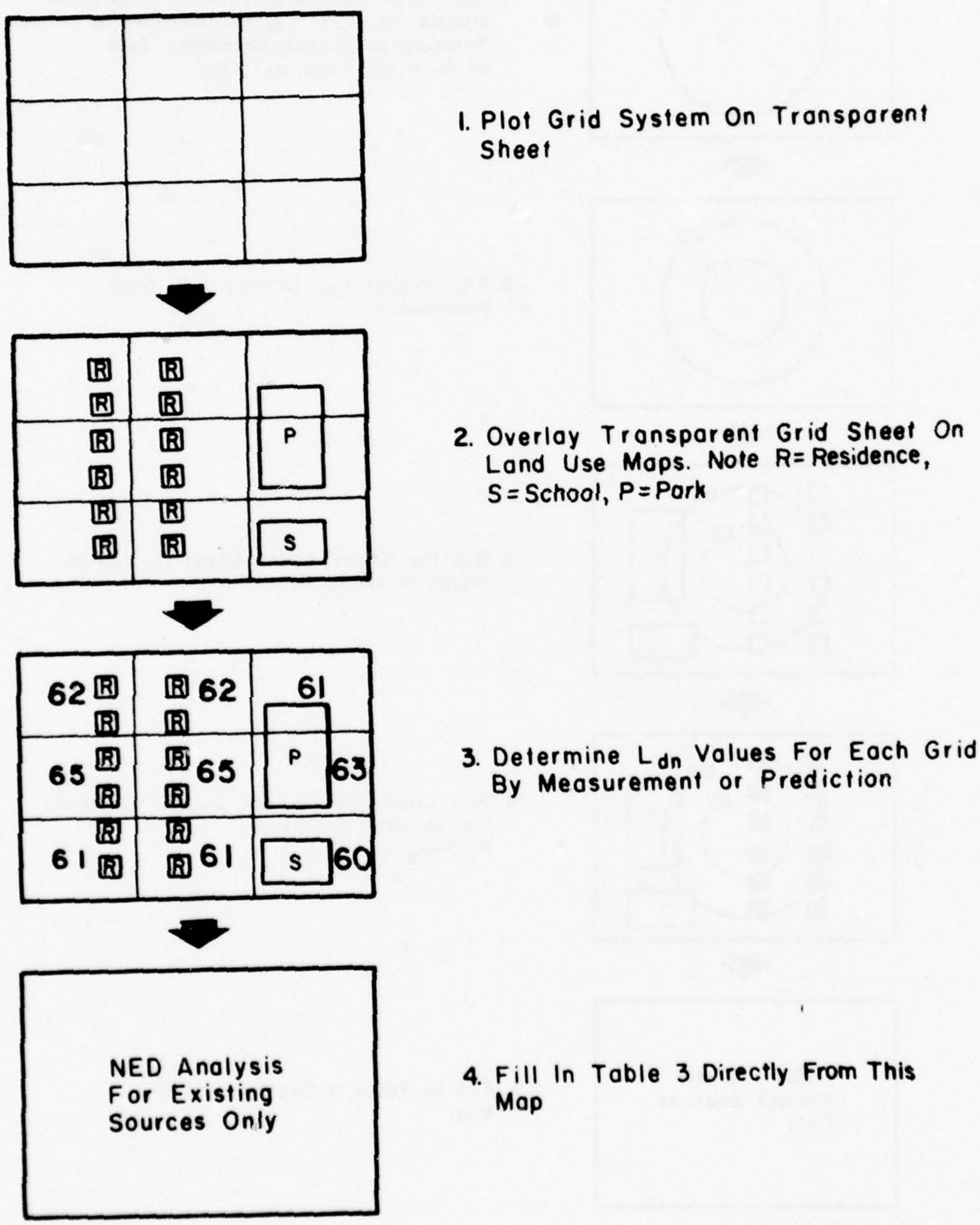


Figure 11. NED analysis for existing sources without project.

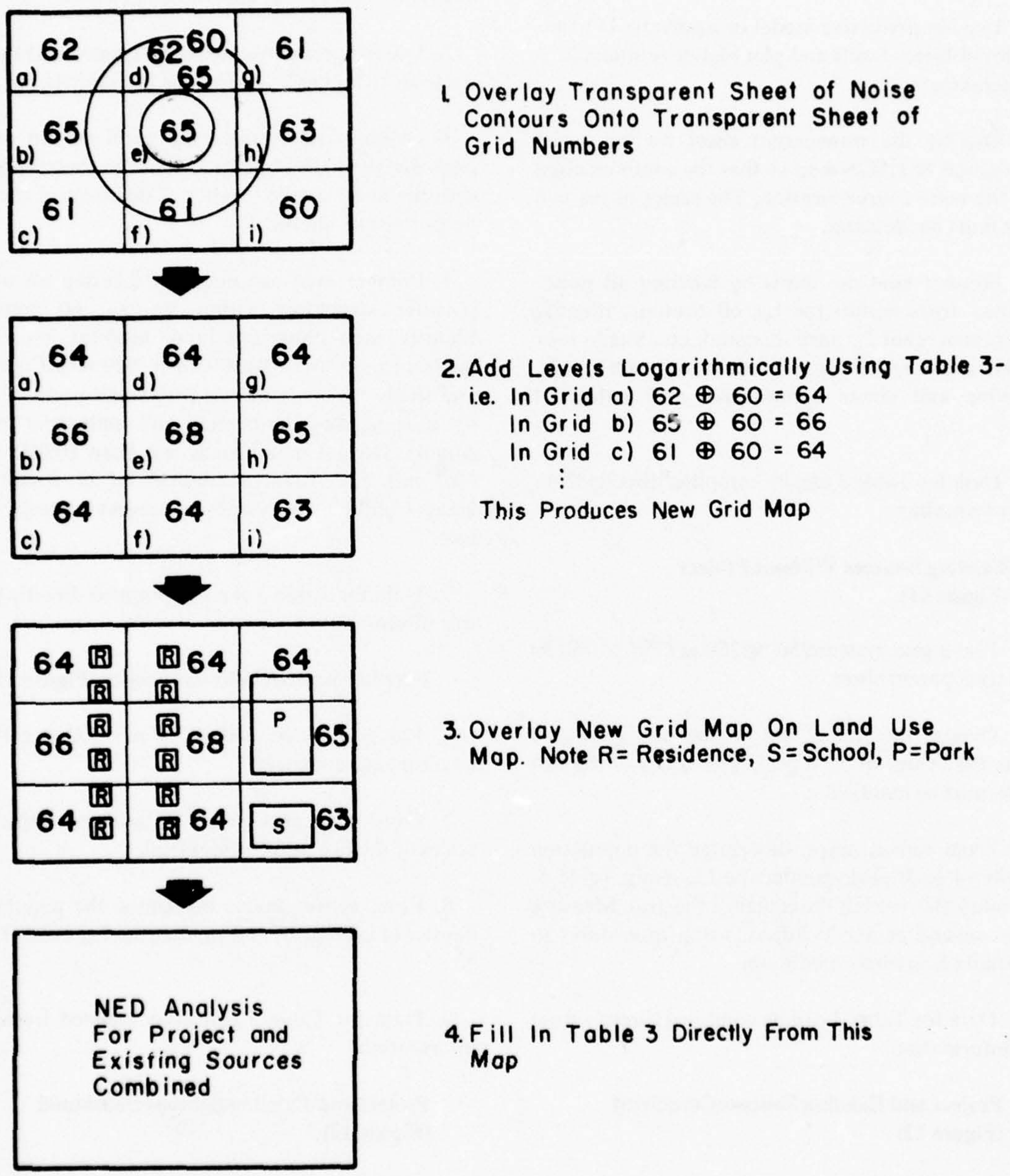


Figure 12. NED analysis for project and existing sources combined.

Project Sources (Figure 10)

1. Use the predictive model in Appendix D to calculate the distance to the L_{dn} 60 contour. Plot this contour on a transparent sheet. The area encompassed by this contour determines the type of analysis. (For this example, the area is assumed to be between 10^6 sq ft [92 903 m²] and 5 sq mi [12.8 km²]; thus, a Type II analysis is applied.)

2. Use the predictive model in Appendix D to adjust for different levels and plot higher contours in 5-dB increments.

3. Overlay the transparent sheet on the aerial photograph or USGS map so that the contours align with the noise source location. The scales of the two maps must be identical.

4. Prepare land-use maps by labeling all noise-sensitive areas within the L_{dn} 60 contour. Identify each school, church, park, hospital, etc. Shade residential areas rather than pinpointing each house. Combine and shade commercial with industrial areas.

5. Data for Table 3 can be compiled directly from this information.

Existing Sources Without Project (Figure 11)

6. Plot a grid system 250 × 250 m (750 × 750 ft) on a transparent sheet.

7. Overlay the grid system on land-use maps and locate the center of each grid. The scales of the two maps must be identical.

8. From census maps, determine the population density of each grid, predict the L_{dn} using Table 5, and mark this level in the center of the grid. Measure L_{dn} at several center locations, using procedures in Appendix E to verify prediction.

9. Data for Table 3 can be compiled directly from this information.

Project and Existing Sources Combined (Figure 12)

10. Same as steps 12 through 15 for the Type I analysis.

Type III Analysis (Opening New Artillery Range)

Project Sources Only (Figure 10)

1. Use the predictive model in Appendix D to plot L_{dn} 60 contours for the planned operation on a transparent sheet. The area encompassed by this contour determines the type of analysis. (For this example, the area is assumed to be more than 5 sq mi [12.8 km²]; thus, a Type III analysis is applied.)

2. Use the predictive model in Appendix D to plot contours to higher levels in 5-dB increments.

3. Overlay the transparent sheet on an aerial photograph or USGS map so that the contours align with the noise source location. The scales of the two maps must be identical.

4. Prepare land-use maps by labeling all noise-sensitive structures within the L_{dn} 60 contour. Identify each church, school, hospital, etc., and parks of more than 10,000 sq ft (929 m²). Combine and shade residential areas with small parks. Classify and shade commercial and industrial areas equally. Do not detail areas less than 10,000 sq ft (929 m²), i.e., isolated commercial or residential areas. Combine them with the largest adjacent land use.

5. Data for Table 3 can be compiled directly from this information.

Existing Sources Without Project (Figure 11)

6. Plot grid system 500 × 500 m (1500 × 1500 ft) on a transparent sheet.

7. Overlay the grid system on land-use maps. The scales of the two must be identical.

8. From census maps, determine the population density of each grid, and predict the L_{dn} using Table 5.

9. Data for Table 3 can be completed from this information.

Project and Existing Sources Combined (Figure 12)

10. Same as steps 12 through 15 for the Type I analysis.

Type III Analysis (Expanding Artillery Range Operations)

A base is planning to expand its existing artillery range operations.

Project Sources Only (Figure 10)

1. Use the predictive model in Appendix D to plot L_{dn} 60 contours for the planned operation on a transparent sheet. The area encompassed by these contours determines the type of analysis. (For this example, the area is assumed to be more than 5 sq mi [12.8 km^2]; thus, a Type III analysis is applied.)

2. Use the predictive model in Appendix D to plot contours to higher levels in 5-dB increments.

3. Overlay the transparent sheet on an aerial photograph or USGS map so that the contours align with the noise source location. The scales of the two maps must be identical.

4. Prepare land-use maps by labeling all noise-sensitive structures within the L_{dn} 60 contour. Identify each church, school, hospital, etc., and parks of more than 10,000 sq ft (929 m^2). Combine and shade residential areas with small parks. Classify and shade commercial and industrial areas equally. Do not detail areas that have less than 10,000 sq ft (929 m^2), i.e., isolated commercial or residential areas. Combine them with largest adjacent land use.

5. Data for Table 4 can be compiled directly from this information.

Existing Sources Without Project (Figure 11)

6. Plot grid system 500 × 500 m (1500 × 1500 ft) on a transparent sheet.

7. Overlay the grid system and land-use maps. The scales of the two must be identical.

8. From census tracts, determine the population density of each grid, and predict the L_{dn} using Table 5.

9. Use predictive models in Appendix D to plot L_{dn} contours of the existing operation in 5-dB increments on a transparent sheet. Overlay the transparent sheet on the grid system and land-use maps so that the contours align with the noise source location. The scales of all three maps must be identical.

10. Where contours intersect grids, add two levels logarithmically using Table 10, and apply this new number as the L_{dn} grid value. Use these values to prepare a new transparent sheet.

11. Overlay the new sheet on the land-use map. The scales of the two maps must be identical.

12. Data for Table 3 can be compiled for the existing sources only from this information.

Project and Existing Sources Combined (Figure 12)

13. Same as steps 12 through 15 of the Type I analysis.

Summary

The four examples discussed in the previous section provide flexible guidelines for creating and combining the noise contour and land-use maps. Although there are distinct differences among the techniques of the three types of analyses, the individual steps can be interchanged to allow coverage of all possible situations. While a 60 L_{dn} criterion is used, either higher or lower levels can be applied, depending on the intent of the EIA/EIS and the interpretation of the levels in Appendix C.

Perhaps the biggest difference in the three analysis types is the detail involved in preparing the land-use maps. This difference (Figure 13) is caused mainly by the economic and time considerations used in scrutinizing a relatively small area as opposed to an area of several thousand square kilometers. In any event, the tables and figures presented in this section fit into the EIA/EIS format as shown in Table 14.

4 MITIGATION TECHNIQUES

Point 5 of the CEQ guidelines requires an analysis on how avoidable impacts will be mitigated. The purpose of this section is to present a basic outline of the fundamental approaches to noise control. They can be grouped into the following three categories.

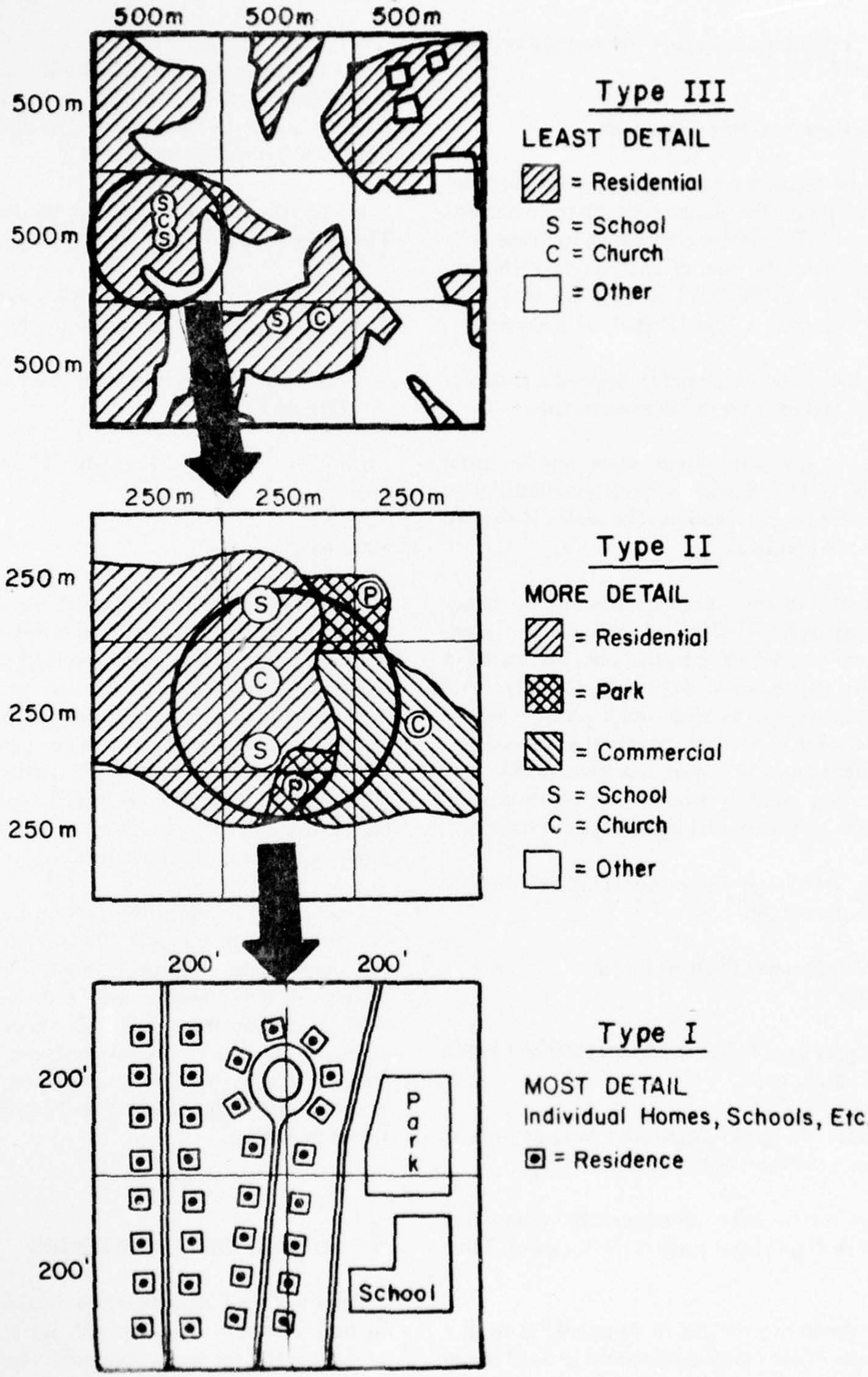


Figure 13. A comparison of the land-use maps needed for the three types of NED analysis.

Table 14

Summary of Recommended Information to Be Included in EIA/EIS (3)

(Figures and tables already addressed in text are in bold type.)

CEQ Guideline Point	Summary Information to be Supplied in Main Text	Data Sources to be Supplied in Appendix to EIA/EIS*
1	Describe project in terms of major sources, their location and their emissions	Fig. **5-9, 11**
	Describe existing environment in terms of noise levels and land uses (supply contour maps)	Tables **3, 5, 6, 13**
2	Identify possible areas of conflict with current and proposed land uses.	Fig. **1, 2, 3, 10**
	List planned steps to reduce impact	Table 15
3	Describe and quantify probable noise impact of proposed action	Fig. **2, 10, 12** Tables **3, 6,** C2, C3
4	Describe and quantify probable noise impact of alternative actions	Same as in points 1 to 3
5	Quantify impact after mitigation techniques have been applied	Fig. **2, 10, 12** Tables **3, 6,** 15, C2, C3
6	Compare positive, short-term effects with detrimental, long-term effects	
	Compare positive, long-term effects wth detrimental short-term effects	
7	Describe cultural and natural areas that will be permanently impacted by the action	Fig. **2** Tables **3, 6**
8	Use DA-PAM-200-1 to satisfy this requirement	

*Data sources should be referenced in main text and then appended. In addition, appendix should contain description of all methodologies used to obtain data.

1. *Source Quieting* — A design modification which reduces the amount of noise emanating from a source, or a change in the operation of a source which does not reduce the absolute level of the noise created, but reduces the level perceived by the receiver.

2. Noise Path Alteration — A change in the noise path which reduces the level of noise reaching the receiver, but not the level created.

3. Receiver Modification — A change in the physical environment of the receiver which reduces the level of noise perceived, but not the level created.

A summary of these approaches is listed in Table 15. The table is a matrix with noise sources listed on one axis and mitigation techniques on the other. An "X" indicates when a technique applies to a particular source. The reduction techniques are divided into the source-path-receiver approach listed above. While all the techniques have been listed, it should be stated that not all of them are applicable to each source. For example, use of meteorological conditions can only be applied to blast and artillery noise, while relocating can be applied to almost all the sources.

While each technique is discussed separately, the mitigation of any source will require an extensive study of all possible approaches. In some cases, the optimum mitigation technique may combine several approaches. Each technique should also be reviewed in terms of its feasibility, cost, and noise reduction potential. Unfortunately, since few of the techniques listed have been quantified in these areas, only general approaches will be presented herein. As more information is documented, it will be made available in future publications.

Source Quieting

There are two source quieting approaches. The first is a design modification which will reduce the actual noise level emanating from the source. The second is an operational change which will not reduce the level emitted, but will reduce the level perceived by the receiver. Although listed herein, the first approach is not as realistic as the second for actual field use. For example, a facility engineer cannot realistically eliminate a helicopter noise problem by redesigning the engine, but the noise may be somewhat ameliorated by changing routes, altitudes, or schedules.

Design Modification

In most situations, noise can be effectively reduced at the source through proper initial design. However, for fixed sources in industrial or construc-

Table 15

Mitigation Techniques Vs. Noise Source

Mitigation Techniques: Class	Type	Noise Source: Artillery/Blast	Pistol Range	Rotary Wing	Combat Vehicle	Private Vehicle	Fixed Wing	Railroad	Construction	Fixed Source	Ground Run-ups
SOURCE	Design Modification	X	X	X	X		X	X	X	X	X
	Retrofitting	X	X	X	X		X		X	X	X
	Maintenance			X	X		X		X	X	
	Simulators	X	X	X	X		X				
	Relocate/Reroute	X	X	X	X	X	X	X		X	X
	Reschedule	X	X	X	X	X	X	X		X	X
	Meteorological	X									
	Operational	X		X	X	X	X		X	X	X
PATH	Barriers/Enclosures	X	X		X	X		X	X	X	X
RECEIVER	Architectural Design	X	X	X	X	X	X	X	X	X	X
	Relocate	X	X	X	X	X	X	X	X	X	X

tion operations, several limited measures can be taken:

1. Elimination of impacting surfaces
2. Balancing of moving parts
3. Reduction of friction
4. Application of dynamic absorbers
5. Vibration isolation
6. Alteration of natural frequency of system
7. Structural damping
8. Isolation of large radiating panels
9. Perforations in large radiating panels.

Changing the route design of sources that travel on fixed paths can significantly reduce noise. Specifically for railroads:

1. Using welded rails reduces noise by 8 dB
2. Grinding rails flat and smooth reduces noise by 1 to 2 dB
3. Coating rail heads with damping compound reduces vibrations
4. Using concrete track beds is quieter than using wooden ties and ballast
5. Eliminating tight curves reduces noise by 5 to 15 dB.

Specifically for traffic noise:

1. Smoothing an unusually rough surface reduces noise by 5 dB
2. Eliminating grades reduces truck noise.

Retrofitting

Retrofitting consists of:

1. Use of mufflers on all on-post private vehicles
2. Use of mufflers, engine shrouds, etc. on all combat vehicles

3. Use of noise suppressors for engine testing at airfields

4. Use of silencers for selected artillery.

While the first three have been employed successfully, silencers for artillery are still in the research and development stage.

Maintenance

Although maintenance programs will partially control noise from street vehicles, most vehicles using installation roads will not be subject to direct installation control. However, such programs can be useful for ameliorating noise from poorly maintained combat vehicles. Auxiliary equipment such as pumps and compressors should also be kept in working order.

Simulators

Since most Army artillery and flying activities are for training purposes, many operations can be replaced or reduced by using training simulators. Some simulators are already in operation, and current development trends are toward more sophisticated designs. Besides the noise reduction, savings in fuel and ammunition can be achieved.

Relocate/Reroute

This category involves optimizing the location of noise activities in relation to noise-sensitive areas. There are several approaches: (1) dispersing operations will increase the area affected but decrease the severity of the effects; (2) concentrating these operations into a compact area will decrease the amount of land affected while increasing the severity of the impact. Figure 14 illustrates dispersion of aircraft flight paths to reduce the adverse impact caused by a single flight path. Notice, however, that more land area, although not sensitive, is now affected by the activity.

In addition, operations can be located near nonsensitive areas instead of near schools and residences. Also, the location of a noisy activity can be changed according to the time of day. For example, noisy operations can be located at night in areas used only during the day, such as near schools, churches, and work areas. Similarly, seasonal changes can reduce the effects of noisy activities on facilities which are used only seasonally, e.g., outdoor amphitheaters or stadiums.

Reschedule

There are three basic scheduling approaches:

1. Limit number/duration of operations

2. Distribute number of operations evenly over time period

3. Limit number of night operations.

Limit Number/Duration. Two equations for calculating L_{eq} were developed in Chapter 3 for continuous (Eq 12) and intermittent (Eq 10) noise sources:

$$L_{eq} = AL + 10 \log_{10} D - 35.6 \quad \text{[Eq 12]}$$

$$L_{eq} = SEL + 10 \log_{10} N \quad \text{[Eq 10]}$$

Reducing the number (N) or the duration (D) of operations will reduce the noise impact. As illustrated in Figure 15, a decrease in the number/duration of an operation by a factor of 10 (final duration ÷ initial duration = 10) results in a 10-dB decrease in the L_{eq} value. Similarly, a decrease by a factor of 2 yields a 3-dB reduction.

Distribute Evenly. Proper scheduling can minimize periods of peak activity which result in high noise levels. For example, an installation having 10,000 operations per month may have 200 one day, 1000 the next, etc. If the numbers were dispersed evenly over 30 days per month, there would be 333 a day. From Figure 15, the L_{eq} value would be 5 dB less than on days with 1000 operations (1000/333 = a factor of 3 decrease), but 2 dB higher than on days with 200 operations (333/200 = a factor of 1.6 increase). It should be stated that while this approach can reduce peaks, it will not alter the total monthly noise exposure.

Limit Nighttime Operations. People are more sensitive to night noise, as indicated by the 10-dB penalty imposed on nighttime operations by the L_{dn} equations for continuous (Eq 11) and intermittent (Eq 14) sources.

$$L_{dn} = SEL + 10 \log_{10}[N_d + 10N_n] - 49.4 \quad \text{[Eq 11]}$$

$$L_{dn} = AL + 10 \log_{10}[D_d + 10D_n] - 49.4 \quad \text{[Eq 14]}$$

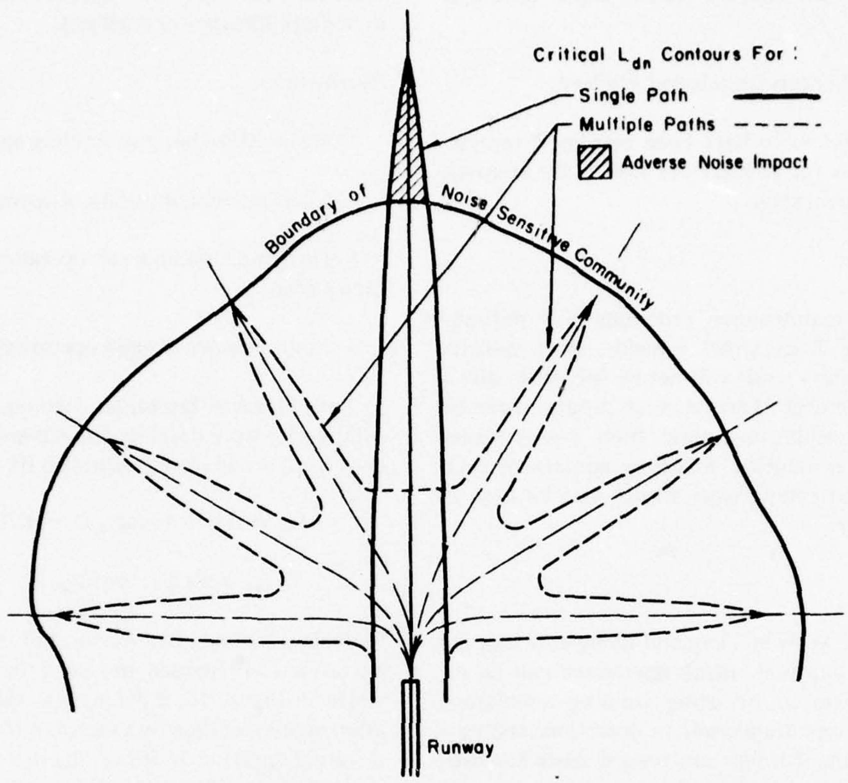
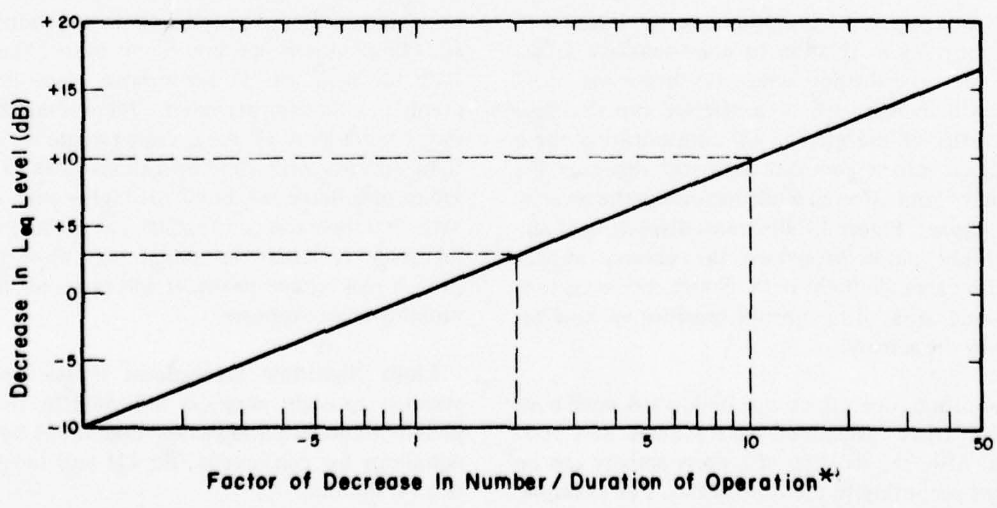


Figure 14. Effect of route dispersion on noise impact. (From *Planning in the Noise Environment*, Draft Joint Services Planning Manual [December 1976].)



*Determined by the ratio of the initial number of operations to the final number, or the initial duration of operation to the final duration.

Figure 15. Effect of operation number/duration ratio on L_{eq} level.

Thus, reducing nighttime operations will significantly reduce the L_{dn} value. This reduction can be computed by using Eqs 16 and 17 to determine the effective number/duration of operations for subsequent use in Figure 15.

For intermittent sources

$$EN = N_d + 10N_n \qquad \text{[Eq 16]}$$

where EN = effective number of operations
N_d = number of daytime operations
N_n = number of nighttime operations.

For continuous sources

$$ED = d_d + 10D_n \qquad \text{[Eq 17]}$$

where ED = effective duration of operation
D_d = event duration in seconds during daytime
D_n = event duration in seconds during nighttime.

Example

A base has 100 daily helicopter operations—90 at night and 10 during the day. What is the L_{dn} reduction if 80 night operations are rescheduled for daytime?

Step 1. Determine total number of operations using Eq 16.

Original number = 10 + 90 (10) = 910

Reduced number = 90 + 10 (10) = 190.

Step 2. Determine factor of decrease

Factor = 910/190 = 4.8.

Step 3. From Figure 15, reduction is 6.8 dB.

Meteorological

Noise levels from blasts and artillery fire are significantly affected by the weather. As a result of wind and temperature changes, the speed of sound varies with both direction and altitude. The net result is that the atmosphere sometimes acts as a lens, redirecting waves traveling away from the ground and focusing them at distant points. This focus creates levels that can be 30 dB higher than under more favorable conditions. Severe impact can be thus avoided by scheduling these operations in accordance with specific weather conditions, i.e., limited firing during focusing conditions and unlimited firing during negative gradient and shadow conditions.[15,16] Information of this type can be obtained from weather balloons or by setting up a feedback monitoring system in which a signal is relayed to range control when the noise exceeds a critical decibel level in the community.

Operational

People who directly control the operations of noise sources can help reduce the noise exposure by employing certain operational techniques.

For highway noise:

1. Low speeds will reduce exposure levels for automobiles, but increase them for heavy trucks. The reverse is true for high speeds. The optimum technique depends on vehicle mix.

2. For a 2 to 4 percent mix of trucks, moderate and steady speed freeflow traffic will be quieter than stop-and-go traffic.

For artillery and blast noise:

1. If elevation is optimized, fewer pounds of charge (and therefore less noise) are required to achieve a given distance.

2. Explosions on soft areas such as swamps or crushed earth are less noisy than those on hard areas such as granite.

For airport operations:

1. A steady flow of aircraft minimizes takeoff and landing waiting time and thus reduces noise exposure.

2. Maximum glide angle and high initial altitude to landing approach produce lower noise levels.

---

[15] P. D. Schomer, *Predicting Community Response to Blast Noise*, Technical Report E-17/AD# 773690 (CERL, December 1973).

[16] P. D. Schomer, R. J. Goff, and L. Little, *The Statistics of Amplitude and Spectrum of Blast Propagated in the Atmosphere*, Technical Report N-13/ADA033475 (CERL, November 1976).

3. A reduced thrust at takeoff will lower noise near runways but increase the noise down the flight track as the plane takes longer to reach cruising altitude. On the other hand full throttle for maximum climb angle will lower noise down the flight track but increase noise near the runway. The right technique depends on the land use.

Path Modification

For ground-based sources, placing a physical barrier (walls, earth berms, buildings, or natural terrain) between the noise source and the receiver can provide significant attenuation. To be effective, barriers must be:

1. High enough to break the line of sight between the source and receiver

2. Solid with no gaps or leaks

3. Moderately heavy (surface weight greater than 4 lb/sq ft [19.5 kg/m²])

4. Wide enough to prevent diffraction of sound waves around the edges of the barrier.

A barrier's effectiveness will increase with height, width, and proximity to either source or receiver until a maximum attenuation of 20 dB is achieved.

Landscaping, although aesthetically pleasing, is not an effective barrier unless it has the density and height to obscure the sight of the noise source. A maximum reduction of 10 dBA can be expected for dense vegetation that is at least 10 ft (3 m) higher than the source and at least 200 ft (60 m) thick. Rows of buildings will also provide up to 10 dB attenuation, depending on how the source is shielded both vertically and horizontally.

Both partial and total enclosures can be considered as a kind of barrier, with total enclosures reducing selected sources from 30 to 50 dB. Access openings will usually lessen effectiveness by 10 to 20 dB.

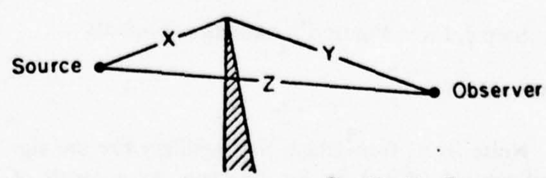
A simplified assessment of barriers is based on a parameter known as path length difference. This quantity, symbolized by δ (delta), is the difference in distance traveled by the sound wave going over the obstruction rather than directly to the observer as it would if the obstacle were not present (Figure 16). Figure 17 can be used to determine the required δ for various reduction needs. For example, if a 10-dB reduction was desired from an adjoining highway, a barrier would have to be designed and located so that the path length difference equalled or exceeded 0.8 ft (.24 m).

Receiver Protection

Ideally, such receiver-oriented approaches as purchasing of land, zoning, and planning to prevent high noise areas from being developed (both on- and off-post) are the best way to avoid noise problems. However, where existing developed areas are already impacted by noise, the receiver-oriented approach is generally an inefficient way to reduce noise.

For example, if one source impacts 100 structures, it would be more efficient to quiet the intrusive source rather than protect the 100 receivers. In addition, while the interior noise levels may become acceptable, the outside environment always remains unacceptable. Thus, protecting the interior of a building whose outdoor environment is integral constitutes only a partial solution. However, since in most cases neither the technology nor the feasibility is available to quiet the source, the receiver approach must be taken. Perhaps the most effective use of receiver protection is in the planning stages of facilities (both on- and off-post) that will be built in high noise areas.

While the techniques herein apply mainly to on-post receivers over which the base commander has control, some transition could be made for off-post usage through coordination with local officials and zoning boards.



$$\delta = X + Y - Z$$

Figure 16. Generalized geometry of acoustic barrier. (From *Highway Noise, A Design Guide for Highway Engineers*, National Cooperative Highway Research Program Report [NCHRP] 117 [NCHRP, 1971].)

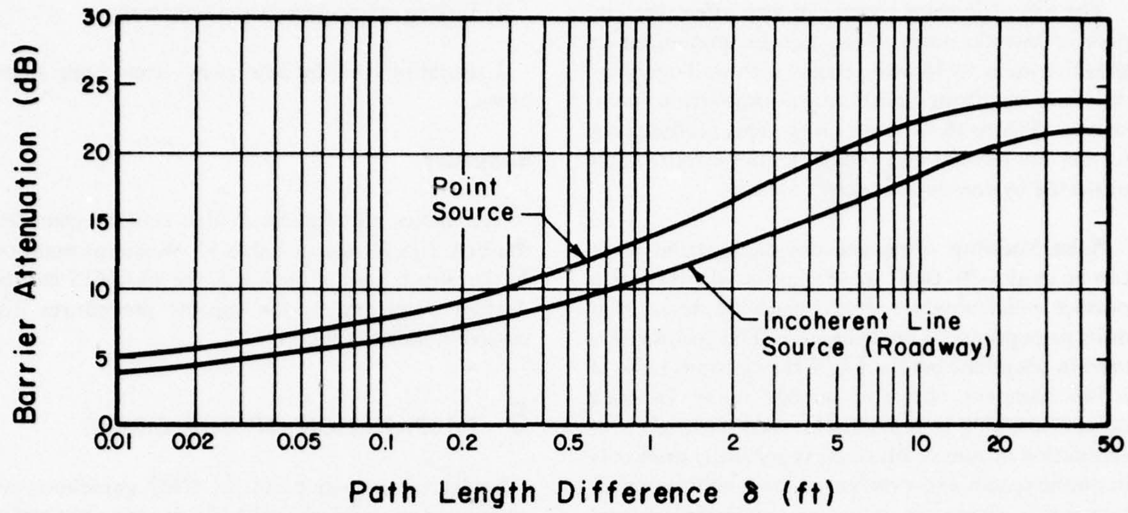


Figure 17. Attenuation of an infinite barrier for point sources and roadways. (From S. E. Wesler, *Manual for Highway Noise Prediction,* # DOT-TSE-FHWA-72-1 [U.S. Department of Transportation, March 1972].)

Architectural Design

Architectural design techniques can be used both to plan new facilities, and to retrofit existing structures. There are three basic categories:

1. Acoustic construction
2. Acoustic design
3. Noise masking.

Acoustic Construction. This method uses extra structural elements to impede sound transmission. While standard elements such as windows, walls, and roofs will mitigate noise somewhat, greater abatement is possible using the techniques shown in Table 16.

Acoustic Design. This method optimizes the shielding of sound waves by means of the structure itself. There are basically two approaches: (1) reduction of openings in surface area (doors, windows, etc.), and (2) use of interior space.

Since the wall of a structure acts as a barrier, its abatement effectiveness will be diminished if there are passages through which sound energy can penetrate. The three most common passages are ventilation ducts, windows, and doors. Relocating, reducing, or eliminating them can minimize intrusion of environmental noise.

Table 16

Acoustic Construction Techniques

(From *Planning in the Noise Environment,* Draft Joint Services Planning Manual [December 1976].)

Element	Construction Technique
Walls	Increase mass
	Use dead air space
	Increase air space width between walls
	Use staggered studs
	Seal cracks and edges
	Use insulation blankets
	Use resilient materials to hold studs and panels together
	Use acoustic coating
Roofs	Increase mass
	Seal cracks and edges
Ceilings	Use insulation blankets
	Use nonfixed suspension methods
	Use acoustical coating
Floors	Increase mass
	Block off joists to prevent noise traveling over or under walls
	Use resilient support between joists and floor
Windows	Seal
	Increase thickness
	Double glaze
	Increase volume of dead airspace in double glazed windows
Doors	Use solid core
	Doorframe gaskets

The use of interior space can also affect the impact of outside noise. Noise can be minimized in sensitive areas by locating rooms with wall openings or those requiring more quiet away from noise sources. Figure 18 illustrates how areas needing protection are located away from the noise source and protected by nonsensitive uses and walls.

Noise Masking. Homogeneous background noise can be used to "soften" unwanted sounds. It is not a positive relief measure, but a cosmetic device that dulls perception of intruding noise. This technique is used in telephone booths where the constant noise of a fan dampens obtrusive outside noise. In open offices, masking is provided by controlled levels of ventilation or music. Masking is generally used only in public spaces and work environments; its application inside residences is not recommended. Sound masking is only effective where the noise intrusions are not extreme, and where the total noise levels (masking plus background levels) do not exceed concentration, sleep, and conversation interference levels.

Relocating

Relocating seeks to optimize the space between the source and receiver to minimize the amount of impact. The strategy is identical to the relocating/rerouting technique described earlier, except that in this case, the receiver is moved, not the source. This can include:

1. Locating the activity/facility to take advantage of natural barriers or other low noise areas

2. Buying existing impacted structures

3. Building the facility away from high noise areas.

Summary

The tables and figures in this chapter complete the EIA/EIS format in Table 17. When information in the appendices is included, the EIA/EIS can be drafted according to the specific procedures discussed in the next chapter.

5 PREPARATION OF THE EIA/EIS

Under the provisions of the CEQ guidelines, an environmental analysis must address the eight major points in Table 18. This section explains how the information obtained in the previous chapters fits into this EIS format. While a few points can be satisfied with simple verbal descriptions, the majority require use of the tables, figures, and charts developed earlier. This is summarized explicitly in Table 17. This analysis addresses itself only to environmental noise.

Major Points of EIA/EIS

If the EICS system has been used, evaluate the output (Example-Figure 1). If evaluation indicates that there is no potential impact for the proposed action and its alternatives, make this statement in points 2, 3, and 4, and the noise aspect of the EIA/EIS is complete.

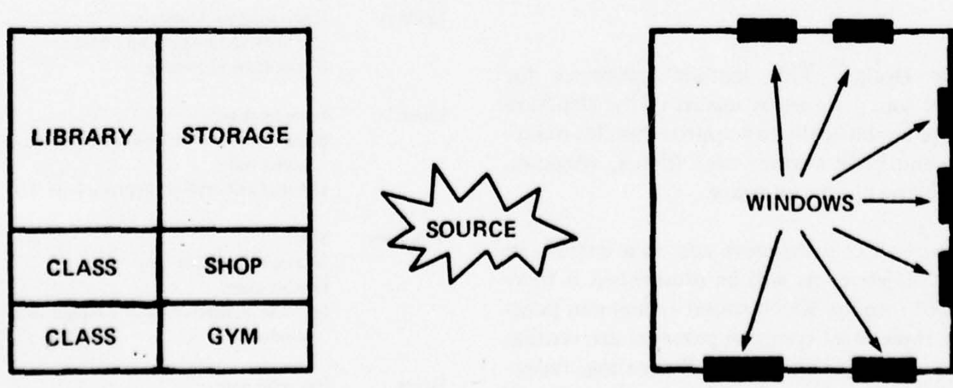


Figure 18. Optimum design layout.

Table 17

Summary of Recommended Information to Be Included in EIA/EIS (4)

(All tables and figures necessary for EIA/EIS have been addressed in text.)

CEQ Guideline Point	Summary Information to be Supplied in Main Text	Data Sources to be Supplied in Appendix to EIA/EIS*
1	Describe project in terms of major sources, their location and their emissions	Fig. 5-9, 11
	Describe existing environment in terms of noise levels and land uses (supply contour maps)	Tables 3, 5, 6, 13
2	Identify possible areas of conflict with current and proposed land uses	Fig. 1, 2, 3, 10
	List planned steps to reduce impact	Table 15
3	Describe and quantify probable noise impact of proposed action	Fig. 2, 10, 12 Tables 3, 6, C2, C3
4	Describe and quantify probable noise impact of alternative actions	Same as in points 1 to 3
5	Quantify impact after mitigation techniques have been applied	Fig. 2, 10, 12 Tables 3, 6, 15, C2, C3
6	Compare positive, short-term effects with detrimental, long-term effects	
	Compare postive, long-term effects with detrimental short-term effects	
7	Describe cultural and natural areas that will be permanently impacted by the action	Fig. 2 Tables 3, 6
8	Use DA-PAM-200-1 to satisfy this requirement	

*Data sources should be referenced in main text and then appended. In addition, appendix should contain description of all methodologies used to obtain data.

If the flowchart in Figure 3 indicates that there is no potential impact for the proposed action and its alternatives, make this statement in points 3 and 4 and the noise aspect of the EIA/EIS is complete.

Table 18

CEQ Requirements for EIA/EIS

From *Handbook for Environmental Impact Analysis*, Pamphlet No. 200-1 [Department of the Army, April 1975].)

1. Project Description
   A. Purpose and description of action
   B. Environmental setting prior to proposed action

2. Land-Use Relationships
   A. Conformity or conflict with land-use plans, policies and controls
      (1) Federal, state, and local
      (2) Approved or proposed

   B. Conflicts and/or inconsistent land-use plans
      (1) Extent of reconciliation
      (2) Reasons for proceeding with action

3. Probable Impact of the Proposed Action on the Environment
   A. Positive and negative effects
   B. Direct and indirect consequences

4. Alternatives to the Proposed Action
   A. Reasonable alternative actions
      (1) Those that might enhance environmental quality
      (2) Those that might avoid some or all adverse effects
   B. Analysis of alternatives

5. Probable Adverse Environmental Effects Which Cannot be Avoided
   a. Adverse and unavoidable impacts

6. Relationship Between Local Short-Term Uses of Man's Environment and the Maintenance and Enhancement of Long-Term Productivity
   a. Trade-off between short-term environmental gains at expense of long-term losses
   b. Trade-off between long-term environmental gains at expense of short-term losses
   c. Extent to which proposed action forecloses future options

7. Irreversible and Irretrievable Commitments of Resources
   a. Natural
   b. Cultural

8. Other Interests and Considerations of Federal Policy that Offset the Adverse Environmental Effects of the Proposed Action
   a. Countervailing benefits of proposed action
   b. Countervailing benefits of alternatives

In all other cases, proceed to point 1.

Point 1 — Project Description

A. Describe the project in terms of major noise sources, including their number, location and emission levels.

1. Identify all major sources associated with activity

2. Locate each source on appropriate map (see Table 12)

3. Tabulate operational information for each source.

4. Draw contours for each source using prediction models in Chapter 3 (Figures 5-9) and Appendix D. Where models do not exist, use measurement procedures in Appendix E.

B. Describe the environmental setting in terms of present land uses and existing noise levels prior to proposed action.

1. Classify all land within area of interest into the following usage categories (both existing and proposed)

a. Residential

b. Commercial/Industrial

c. Noise sensitive structures (schools, hospitals, etc.)

d. Wildlife habitats

e. Cultural sites, scenic views, etc.

2. Plot land-use data on maps.

3. Determine existing levels (Figure 11)

a. Draw grid system over land-use maps (Table 13)

b. Fill in L_{dn} value by prediction (Table 5) or measurement (Appendix E)

4. Quantify the existing noise impact using the NED analysis format in Tables 3 and 6. Verbally describe what is meant by LWP and/or PHL values to clarify the impact for readers unfamiliar with such terms.

a. Compute LWP, Eq 6

b. Compute PHL, Eq 8

Point 2 — Land-Use Relationships

A. Describe how projected noise levels conform or conflict with land uses (existing or proposed) with the following inter-progressional steps. If no impact is indicated for any step, a statement to that effect should be written and the EIA/EIS is completed with regard to noise impact.

1. Overlay noise contour and land use map (Figures 2 and 10)

2. Use Figure 3 flow chart to determine possible impact on people, wildlife, developable land and structures.

B. Describe possible steps to reduce impact (Table 15)

1. Notwithstanding the absence of full reconciliation, explain reasons why action should proceed.

Point 3—Probable Impact of the Proposed Action

A. Describe primary (both beneficial and detrimental) aspects of environmental changes.

1. Overlay noise contours onto land use map (Figures 2 and 10)

2. Combine source contours with existing noise levels (Figure 12)

3. Quantify noise impact with NED analysis (Tables 3 and 6) for project sources only, and project and existing sources combined.

a. Compute LWP, Eq 6

b. Compute PHL, Eq 8

4. Document the impact.

a. People exposed to levels greater than 40 dB, but under criteria of 55 L_{dn}.*

(1) Calculate changes in LWP whenever the background L_{dn} is increased by an activity.

*The 55-dB level is not to be construed as official Army policy. Because it is only the recommendation of the authors and subject to change, final implementation should be coordinated with the user's major command and the DA Environmental Office.

(2) Describe verbally the general degradation caused by the change in the noise environment but state that no health and welfare effects are expected to occur because the levels are so low.

b. People exposed to levels above the impact criteria of 55 but under 75 dB L_{dn}.*

(1) Calculate changes in LWP for quantifying:

(a) Before and after noise exposure of the same area or population.

(b) Noise impact from different noise sources.

(c) Noise impact from different actions for different areas. (For this comparison, the population and/or area must be defined precisely.

(2) Describe verbally the general degradation caused by the change in the noise environment.

c. People exposed to L_{dn} levels of more than 75 dB.

(1) Calculate the change in PLH. Emphasize the possibility of severe health and welfare problems in residential areas using PHL as an indicator of the degree of severity.

d. Animals exposed to noise.

(1) Describe the changes in the noise environment with detail on the exposure of any specific species of animals.

(2) Detail the effects of abnormally high sound levels on endangered species, and domestic or wild animal populations. Where both people and animals are impacted in the same area, the quantitative assessment of impact on humans is considered sufficient to assess the noise impact on animals.

e. Special situations

(1) Describe the noise environment for each noise-sensitive structure (Tables 3 and 6). Review the significance of the increase in noise levels in monetary terms.

(2) Describe the noise environment for undeveloped and developed noise-sensitive land areas (Tables 3 and 6). Identify designated wilderness areas as special situations. Describe how the noise will affect these areas.

f. Miscellaneous assessments

(1) Compliance with environmental legislation (p 26)

(2) Vibration (see Appendix F)

(3) Temporary noise environment (p 25)

(4) Land-use planning (p 26)

(5) Population movement (p 26)

(6) Adding new source to high noise area (p 26)

g. Use information in Appendix C to explain what each level means:

(1) Health and welfare effects (Table C2)*

(2) Physiological damage (Table C3)

(3) Miscellaneous degradation (Table C2)

B. Secondary Effects

These include population concentration and growth. Many actions attract people to previously unpopulated areas and indirectly cause pollution, congestion, and land development that probably would not have otherwise occurred. At the present time, there are no procedures available to quantify these effects. Thus, a verbal summary is adequate.

Point 4 — Alternatives to the Proposed Action

A. If it is determined that there is no significant environmental impact from a preferred course of action, there is no need to assess alternative courses of action. On the other hand, when there are several

*The 55 dB level is not to be construed as official Army policy. Because it is only the recommendation of the authors and subject to change, final implementation should be coordinated with the user's major command and the DA Environmental Office.

*The 55 dB level is not to be construed as official Army policy. Because it is only the recommendation of the authors and subject to change, final implementation should be coordinated with the user's major command and the DA Environmental Office.

courses of action which are equally acceptable, an attempt should be made to identify the alternative which will have the least environmental impact. In addition, if a significant noise impact is not identified for the preferred action, alternative proposals may be necessary to mitigate other impacts (air, water, etc.). All reasonable alternatives should be considered, especially those that might enhance environmental quality or those that might avoid some or all adverse effects.

B. Using procedures outlined in Points 1 through 3, quantify the impact on each alternative.

Point 5 — Probable Adverse Environmental Effects Which Cannot Be Avoided

A. Describe how adverse effects previously discussed will be mitigated.

1. Select specific mitigation techniques (Table 15).

2. Repeat steps in Point 1 using results of these techniques to change either contours or land use maps.

3. Quantify the impact using steps in Point 3.

4. Summarize those probable effects which cannot be avoided should the proposal be implemented.

Point 6 — Relationship Between Local Short-Term Uses of Man's Environment and the Maintenance and Enhancement of Long-Term Productivity

A. Discuss positive aspects of proposed action on a short-term basis and compare these with detrimental long-term effects. For example, construction of a new highway may relieve congestion, but increased noise levels may destroy tranquil areas.

B. Discuss positive aspects of the proposed action on a long-term basis and compare these with detrimental short-term effects. For example, construction of a sewage treatment plant may create noise, but long-term aspects of the project include enhanced water quality.

C. Assess the cumulative and long-term impacts of the proposed action with the view that each generation is a trustee of the environment for succeeding generations. Consider such losses as restrictions on visitations of historic or archaeological sites, destruction of natural vistas or increased danger to threatened species.

Point 7 — Irreversible and Irretrievable Commitments of Resources

A. Natural Resources—Discuss the irrevocable loss of natural resources caused by implementation of the proposed action. Include effects such as ecosystem imbalance, destruction of wildlife habitats, or loss of natural land-use patterns (Tables 3 and 6).

B. Cultural Resources—Discuss the irrevocable loss of cultural resources caused by implementation of proposed action. Include such areas as human interest sites, archaeological sites or scenic views (Tables 3 and 6).

1. Review these losses in terms of lasting social and economic effects on surrounding communities.

Point 8 — Other Interests and Considerations of Federal Policy That Offset the Adverse Environmental Effects of the Proposed Action

Describe for the project and each alternative such positive aspects as improving the U.S. defense posture, saving money, improving military management, etc. Include any environmental benefits from Point 3. These considerations are to be balanced against any negative environmental impacts identified in Points 3 and 5. In addition, discuss mitigation procedures from Point 5 which will reduce project impacts *compared to impacts of current and ongoing projects*, or which will conserve energy resources by using insulation in buildings or other structures (when such insulation provides acoustical protection as well as preventing heating/cooling losses). DA Pamphlet 200-1[17] should be examined for additional guidance.

Summary of Required Information

Table 17, which was described earlier, summarizes the information generated from this manual (contours, tables, figures, etc.) in terms of addressing the essential points of an EIA/EIS.

Because this manual provides detailed information for defining the impact of only one major envi-

[17] *Handbook for Environmental Impact Analysis*, Pamphlet No. 200-1 (Department of the Army, April 1975).

ronmental category—*noise*—it must be remembered that the total requirement is to take an interdisciplinary approach in assessing total environmental impact. For example, in discussing alternatives to reduce the noise impact, the fact that other impacts (e.g., air, water, ecology) may either increase or decrease must be considered. It is important that these checks and balances between all environmental areas be considered in the CEQ guidelines. A proper use of all of the tools available, including the computer model developed by CERL[18-23] and DA Pamphlet 200-1,[24] will insure that such an approach is taken.

6 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This user manual provides quantitative procedures for evaluating the environmental impacts from noise emissions for Army military activities. The combination of material from this manual with material from the CERL-developed computer systems should produce an integrated approach to preparation of high-quality EIAs/EISs.

Recommendations

It is recommended that this manual be used by personnel involved in preparing environmental impact assessments and statements for projects having definite noise impacts.

---

[18] L. V. Urban, H. E. Balbach, R. K. Jain, E. W. Novak, and R. E. Riggins, *Computer-Aided Environmental Impact Analysis for Construction Activities: User Manual*, Technical Report E-50/ADA008988 (CERL, March 1975).

[19] R. E. Riggins and E. W. Novak, *Computer-Aided Environmental Impact Analysis for Mission Change, Operations and Maintenance, and Training Activities: User Manual*, Technical Report E-85/ADA022698 (CERL, February 1976).

[20] E. W. Novak, S. E. Thomas, R. A. Mitchell, and R. E. Riggins, *Computer-Aided Environmental Impact Analysis for Industrial, Procurement, and RDT&E Activities: User Manual*, Draft Technical Report (CERL).

[21] *Environmental Impact Computer System Attribute Descriptor Package Reference Document*, Technical Report E-86/ADA 024303 (CERL, April 1976).

[22] R. L. Welsh, *User Manual for the Computer-Aided Environmental Legislative Data System*, Technical Report E-78/ADA 019018 (CERL, November 1975).

[23] R. D. Webster, et al., *The Economic Impact Forecast System: Description and User Instructions*, Technical Report N-2/ADA027139 (CERL, June 1976).

[24] *Handbook for Environmental Impact Analysis*, Pamphlet No. 200-1 (Department of the Army, April 1975).

REFERENCES

A Basis for Limiting Noise Exposure for Hearing Conservation, 550/9-73-001-A (U.S. Environmental Protection Agency [USEPA], 1973).

AR 200-1, *Environmental Protection and Enhancement* (Department of the Army, 28 December 1976).

Bartel, C., C. Couglin, J. Moran, and L. Watkins, *Airport Noise Reduction Forecast, Vol II, NEF Computer Program Description and User's Manual*, Report # DOT-TST-75-4 (Department of Transportation, 1975).

Community Noise, NTID 300.3 (USEPA, 1971).

Community Noise Exposure Resulting From Aircraft Operations, AMRL-TR-73-10 C Series (Aerospace Medical Research Laboratory, 1971).

Community Noise Monitoring—A Manual for Implementation, Technical Report WR-76-8 (Wyle Laboratories, July 1976).

Environmental Impact Computer System Attribute Descriptor Package Reference Document, Technical Report E-86/ADA024303 (U.S. Army Construction Engineering Research Laboratory [CERL], April 1976).

Guidelines for Preparing Environmental Impact Statements on Noise, Draft Report of CHABA Working Group Number 69 (Committees on Hearing and Bioacoustics, February 1977).

Handbook for Environmental Impact Analysis, Pamphlet No. 200-1 (Department of the Army, April 1975).

Highway Noise, A Design Guide for Highway Engineers, National Cooperative Highway Research Program Report (NCHRP) 117 (NCHRP, 1971).

H.M.S.O. Second Survey of Aircraft Noise Annoyance Around London (Heathrow) Airport (1971).

Homans, B., J. McBryan, and P. Schomer, *User Manual for the Acquisition and Evaluation of Operational Blast Noise Data*, Technical Report E-42/AD# 782911 (CERL, July 1974).

Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety, 550/9-74-004 (USEPA, March 1974).

Noise From Construction Equipment and Operations, Building Equipment and Home Appliances, NTID 300.1 (USEPA, 1971).

Novak, E. W., S. E. Thomas, R. A. Mitchell, and R. E. Riggins, *Computer-Aided Environmental Impact Analysis for Industrial, Procurement, and RDT&E Activities: User Manual*, Draft Technical Report (CERL).

Planning in the Noise Environment, Draft Joint Services Planning Manual (December 1976). (To be completed and distributed under Army TM 5-803-2 and other service identification numbers.)

Population Distribution of the United States as a Function of Outdoor Noise Level, EPA 550/9-74-009 (USEPA, June 1974).

Predicting the Noise Impact From Small Propeller-Driven Fixed-Wing Aircraft Operations, Draft Technical Letter (Office of the Chief of Engineers [OCE], 1974).

"Preparation of Environmental Impact Statements: Guidelines," *Federal Register*, Vol 38, No. 147, Part II (August 1, 1973), pp 20550-20562.

Riggins, R. E. and E. W. Novak, *Computer-Aided Environmental Impact Analysis for Mission Change, Operations and Maintenance, and Training Activities: User Manual*, Technical Report E-85/ADA022698 (CERL, February 1976).

Schomer, P. and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses*, Interim Report N-10/ADA031450 (CERL, September 1976).

Schomer, P. D., *Predicting Community Response to Blast Noise*, Technical Report E-17/AD # 773690 (CERL, December 1973).

Schomer, P. D., R. J. Goff, and L. Little, *The Statistics of Amplitude and Spectrum of Blast Propagated in the Atmosphere*, Technical Report N-13/ADA033475 (CERL, November 1976).

Schultz, T. and N. McMahon, *HUD Noise Assessment Guidelines*, BBN Report 2176 (BBN, August 1971).

Urban, L. V., H. E. Balbach, R. K. Jain, E. W. Novak, and R. E. Riggins, *Computer-Aided Environmental Impact Analysis for Construction Activities: User Manual*, Technical Report E-50/ADA008988 (CERL, March 1975).

Webster, R. D., et al., *The Economic Impact Forecast System: Description and User Instructions*, Technical Report N-2/ADA027139 (CERL, June 1976).

Welsh, R. L., *User Manual for the Computer-Aided Environmental Legislative Data System*, Technical Report E-78/ADA019018 (CERL, November 1975).

Wesler, S. E., *Manual for Highway Noise Prediction*, # DOT-TSE-FHWA-72-1 (U.S. Department of Transportation, March 1972).

APPENDIX A:

GLOSSARY:

absorption: The change of sound energy into some other form, usually heat, when it passes through a medium or strikes a surface.

acceleration: The time-rate-of-change of velocity, usually described by such modifiers as peak, average, and rms.

acoustics: The science of sound, including its production, transmission, and effects.

A.N.S.I.: American National Standards Institute.

audible range (of frequency): The normal frequency of human hearing, i.e., the frequency range 16 Hz to 20,000 Hz (20 kHz).

average level: A level typical of the levels at a certain place in a stated time period. This is defined by

$$L = 10 \log_{10} \frac{1}{N} \sum_{i=1}^{N} 10^{L_i}$$

where N = number of measurements
L_i = noise level at the i^{th} measurement.

A-weighting: Prescribed frequency response defined by A.N.S.I. Standard S1.4-1971. Used to obtain a single number representing the sound pressure level of a noise in a manner approximating the response of the ear, by de-emphasizing the effects of the low and high frequencies.

A-weighted sound level, A-level (AL): A quantity, in decibels, read from a standard sound-level meter with A-weighting circuitry.

ASEL: A-weighted sound exposure level (see SEL).

composite noise rating (CNR): A measure of the noise produced by aircraft operations over a 24-hour annual average busy day. The CNR is calculated from aircraft noise and the number of operations in daytime and nighttime periods.

C-weighting: Prescribed frequency response defined by A.N.S.I. Standard S1.4-1971. Slightly de-emphasizes low- and high-frequency ranges.

C-weighted sound level, C-level (CL): A quantity, in decibels, read from a standard sound level meter with C-weighting circuitry.

confidence limits: The upper and lower values of the range over which a given percent probability applies. For example, if the chances are 99 out of 100 that a sample lies between 10 and 12, the 99 percent confidence limits are said to be 10 and 12.

continuous noise: On-going noise whose intensity remains at a measurable level (which may vary) without interruption over a specified period of time.

CSEL: C-weighted sound exposure level (see SEL).

daytime: the hours 0700 to 2200.

day-night average sound level: A measure of the noise environment over a 24-hour day. It is the 24-hour A-weighted sound level with a 10-dB weighting applied to the nighttime levels. When equivalent level (L_{eq}) information is available, the L_{dn} is calculated as follows:

$$L_{dn} = 10 \log_{10} \frac{1}{24} [(15)\, 10^{L_d/10} + (9)\, 10^{L_n + 10/10}]\, dB$$

where L_d = L_{eq} for the hours 0700-2200
L_n = L_{eq} for the hours 2200-0700.

decibel (dB): A logarithmic unit of measure of sound (see sound pressure level).

equivalent sound level (L_{eq}): The level of a constant sound which, in a given situation and time period, has the same sound energy as a time varying sound level. While the typical averaging time for the equivalent level is a period of 1 hour, the time period can be altered to meet the user's needs. In equation form:

$$L_{eq} = 10 \log_{10} \sum_{i=1}^{n} f_i 10^{L_i/10} dB$$

f_i = percent of time period in which a particular L_i occurs
L_i = sound level in dB.

fast response: Dynamic characteristics of a sound level meter as defined in A.N.S.I. Standard S1.4-1971.

filter: A device for separating components of a signal on the basis of their frequency. It allows components in one or more frequency bands to pass relatively unattenuated, and it attenuates components in other frequency bands.

frequency: Number of complete oscillation cycles per unit of time. The frequency is the reciprocal of the period. The unit of frequency often used is the Hertz.

frequency analysis (spectrum analysis): A description of an acoustical signal in the frequency domain, resulting in an amplitude level versus frequency plot, commonly obtained in octave bands, ⅓-octave bands, and various narrow bands.

frequency band: Difference in Hertz between the upper and lower frequencies that limit a band, or the interval in octaves between the two frequencies. The band is described by the geometric mean frequency between the two band-edge frequencies; i.e., the 500 Hz octave band describes the band between 707 and 353 Hz.

Gaussian distribution (normal distribution): A particular amplitude distribution of fundamental importance in the theory of probability. It describes many natural phenomena; most stationary acoustic noise that is not periodic has an essentially Gaussian distribution.

Hertz [Hz]: Unit of frequency equal to one cycle per second.

impulse noise: Noise of short duration (typically, less than 1 second) high intensity, abrupt onset, and rapid decay. Impulse noise is characteristically associated with such sources as explosions and the discharge of firearms.

infrasonic: Having a frequency below the audible range for man (below 16 Hz).

intermittent noise: Fluctuating noise whose level falls one or more times to low or unmeasurable values during an exposure.

L_{dn}: See day-night average sound level.

L_{eq}: See equivalent sound level.

level (L): The level of a quantity is the logarithm of the ratio of that quantity to a reference level.

In symbols $L = \log_r (q/q_0)$
r = base of logarithms
q = the quantity under consideration
q_0 = reference level.

logarithmic addition: Combination of sound levels using the logarithmic mathematical function. In equation form:

$$\log(a) + \log(b) = \log[a \cdot b]$$

loudness: The intensive rating of an auditory sensation, in terms of a scale extending from soft to loud. Loudness depends on the sound pressure and on the frequency and wave form of the stimulus.

masking: The process or amount by which the threshold of audibility for one sound is raised by the presence of another (masking) sound.

microphone: An electroacoustic transducer that responds to sound waves and delivers essentially equivalent electric waves.

night: The hours 2200 to 0700.

noise: Any undesired sound.

noise exposure: The cumulative acoustic stimulation reaching the ear of a person over a specified period of time (e.g., a work shift, a day, a working life, or a lifetime).

noise exposure forecast (NEF): A measure of the noise produced by aircraft operations over a 24-hour average busy day. It is based on summation of individual noise events over the 24-hour period, with adjustments applied for nighttime noises and aircraft ground runups. NEF is a scale analogous to CNR.

noise-induced permanent threshold shift (NIPTS): Permanent threshold shift caused by noise exposure, i.e., hearing loss.

noise level: See "sound level."

noise reduction (NR): The difference, in decibels, between the sound level outside a building and the sound level inside a designated room in the build-

ing. NR is dependent on the transmission loss characteristics of the building surfaces exposed to an exterior noise source, the particular noise characteristics of the exterior noise source, and the acoustic properties of the designated room in the building.

normal distribution: See Gaussian distribution.

octave: An interval of sound or vibration having a basic frequency ratio of 2. The preferred series of octave bands for acoustic measurement covers the audible range in ten bands whose center frequencies are 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16,000 Hz.

root-mean square (rms): Square root of the arithmetical mean of the squares of a set of instantaneous amplitudes.

sampling: Transformation of a continuous function into a discrete series of values in appropriate order.

sound: An oscillation in pressure or an auditory sensation evoked by the pressure oscillation.

sound exposure level (SEL): The total energy of a sound accumulated over a given time interval. Technically, it is the weighted sound level (A or C) integrated over the duration of a noise event.

sound level: Sound-pressure level measured in terms of a metering characteristic and weighting (A, B, or C), as specified in A.N.S.I. standard, S1.4-1971.

sound-level meter: An instrument comprising a microphone, amplifier, output meter, and frequency-weighting networks, which is used for the measurement of noise.

sound pressure: A measure of the fluctuating variations in pressure from the static value (i.e., atmospheric pressure) caused by the presence of the sound field. For most complex sound sources the sound pressure contains energy over a broad frequency range audible to humans. The sound pressure at a point is the total instantaneous pressure at that point in the presence of a sound wave minus the static pressure at that point.

sound pressure level [SPL]: In decibels, 20 times the logarithm to the base 10 of the ratio of a sound pressure to the reference sound pressure of 20 micropascals. In equation form:

$$SPL = 20 \log_{10} p/pr$$

where p = sound pressure to be quantified
pr = 20 micropascals.

spectrum: (see frequency analyses).

statistical levels (Lx): The noise level which is exceeded for a stated percentage (x) of the time period of interest.

steady-state sounds: Sounds whose levels remain constant in time.

threshold of audibility: The minimum-sound-pressure level capable of evoking an auditory sensation.

transducer: A device capable of being actuated by waves from one or more transmission systems and supplying related waves to one or more other transmission systems. Examples are microphones, accelerometers, and loudspeakers.

transmission loss (TL): The reduction of airborne sound power that is caused by placing a wall or barrier between the field source and its receiver. Transmission loss is a property of the wall or barrier.

ultrasonic: Having a frequency above the audible range for man, i.e., 20,000 Hz.

wave: A disturbance which is propagated in a medium so that at any point in the medium, the quantity serving as measure of disturbance is a function of the time, while at any instant, the displacement at a point is a function of the position of the point.

wavelength: The distance between a point of a given phase of one wave and a point of the same phase of an adjacent wave.

weighting scales: Prescribed frequency response provided in a sound-level meter, to selectively discriminate against low and high frequencies in accordance with certain equal-loudness hearing characteristics of the human ear.

APPENDIX B:

CHARACTERISTICS OF NOISE

This appendix describes the physics of sound and the current terminology used to describe noise characteristics.

Basic Concepts

An object vibrating back and forth in the atmosphere collides with the surrounding air particles and creates a pressure disturbance. As these air particles collide with other air particles, the pressure disturbance spreads away from the source of vibration. At the ear, this disturbance generates a vibration in the ear-drum, which is transmitted via a network of bones in the ear to the cochlea, which converts the vibration into an electrical signal interpreted by the brain as sound.

The alternate grouping together (compression) and spreading apart (rarefaction) of the particles varies the pressure above and below that of the atmosphere (Figure B1). The distance between successive compressions or successive rarefactions is the wave-length of the sound. The number of times per second that the wave passes from a period of compression through a period of rarefaction and then starts another cycle is the frequency.

The rate at which the molecular displacement occurs is the particle or sound velocity which is 1100 ft/sec (335 m/sec) under normal temperature and pressure conditions.

These various parameters are related by the formula:

$$\lambda = c/f \qquad \text{[Eq B1]}$$

where λ (lambda) = wavelength

c = speed of sound in ft/sec or m/sec*
f = frequency in cycles/sec or Hertz.

*This velocity depends on the gas itself and its absolute temperature. Considering air as the medium of most direct interest:

$$C = 49.07\sqrt{T}\ \text{ft/sec} \qquad \text{[Eq B2]}$$

where T = absolute temperature in degrees Rankine (°R)
°R = °F + 460

or

$$C = 20.03\sqrt{T}\ \text{m/sec} \qquad \text{[Eq B3]}$$

where T = absolute temperature in degrees Kelvin (°K)
°K = °C + 273

Thus, at 70°F (21.1°C), sound propagates at a velocity of 1129.6 ft/sec (343.5 m/sec).

The amplitude of the wavelength is the magnitude of the disturbance from atmospheric pressure.

Decibel Scale

Sound propagating from a simple source can be quantified by measuring the changes it causes in atmospheric pressure. The fluctuation above and below the normal atmospheric pressure is called sound pressure and is the most common measure of a sound's strength.

The ear is sensitive to an exceedingly large range of pressures. For example, the sound pressure generated by a rocket engine may be one billion times the sound pressure of a soft whisper. Because of this large range and the response characteristics of the ear, sound pressure levels (SPL) are usually expressed on a logarithmic scale. In terms of decibels:

$$SPL = 10\log\left(\frac{P}{P_0}\right)^2 \qquad \text{[Eq B4]}$$

where SPL = the sound pressure level in decibels
P_t = the sound pressure of the acoustic signal above atmospheric pressure
P_0 = a reference pressure, standardized at 20 micropascals (this represents the weakest sound that can be heard by an average young undamaged ear).

Table B1 lists several noise sources in terms of both their pressure and decibel levels. Since decibels are logarithmic units, sound levels are not additive. For example, if a single truck produces a sound level of 90 dB at a particular location, two identical trucks would not produce 180 dB. The term $(P/P_0)^2$ is a measure of the energy in the acoustic signal; therefore, addition of sound levels must be performed on an "energy basis."

Example

If one source is 90 dB and a second source is 90 dB, find the total dB value when both sources are operating simultaneously.

Step 1. SPL of first source $10\log(P_t/P_0)^2 = 90$

Step 2. SPL of second source $10 \log (P_2/P_0)^2 = 90$

Therefore, $P_1 = P_2$

Step 3. $SPL_{Total} = 10 \log (P_1/P_0)^2 + 10 \log (P_2/P_0)^2$

$= 10 \log [(P_1/P_0)^2 + (P_2/P_0)^2]$

$= 10 \log 2 (P_1/P_0)^2$ since $P_1 = P_2$

$= 10 \log 2 + 10 \log (P_1/P_0)^2$

$= 3 + 90$ dB

$SPL_{Total} = 93$ dB

Thus, 90 dB $\oplus$ 90 dB = 93 dB*

Table B2 can be used to add different sound levels. For example, to add 90 and 90, the table indicates that 3 dB must be added. To add 90 and 95, 1 dB is added to 95.

When more than two sound levels are added, the levels should be rank-ordered and added two at a

*Note that $\oplus$ indicates logarithmic addition.

Table B1

Comparison of Pressure, Sound Pressure Level, and Common Sounds

Pressure P_0 in Micropascals	SPL in dB*	Loudness
200,000,000	140	Jet aircraft
64,000,000	130	Threshold of pain
20,000,000	120	
6,400,000	110	Near elevated train
2,000,000	100	Inside propeller plane
640,000	90	Full symphony or band
200,000	80	Inside auto at high speed
64,000	70	
20,000	60	Conversation, face-to-face
6,400	50	Inside general office
2,000	40	Inside private office
640	30	Inside bedroom
200	20	
64	10	Inside empty theater
20	0	Threshold of hearing

*SPL as measured on A-scale of standard sound-level meter.

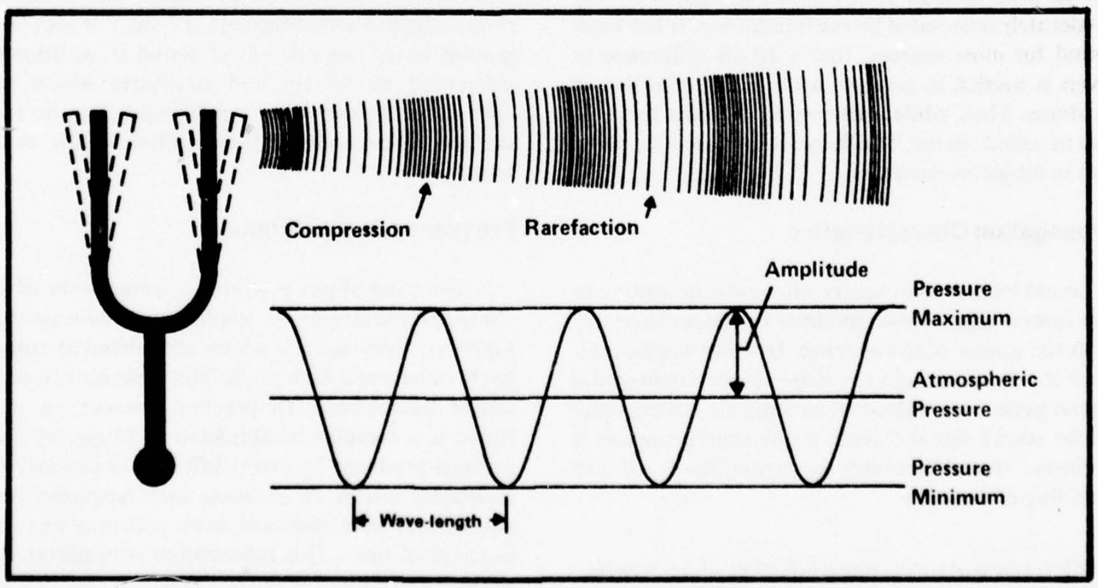


Figure B1. Representation of a sound wave. (From *Planning in the Noise Environment,* Draft Joint Services Planning Manual [December 1976].)

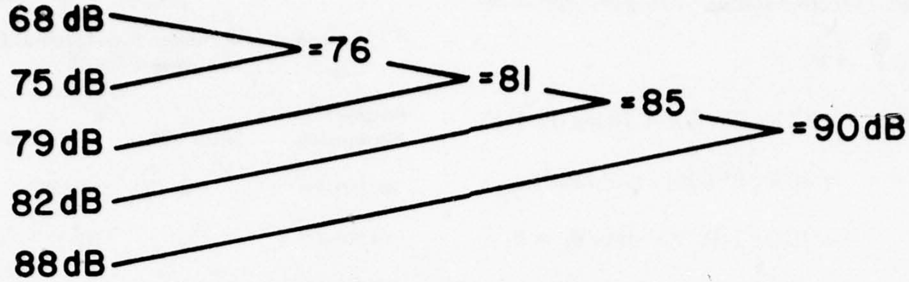


Figure B2. Example of decibel addition.

Table B2

Method for Addition of Sound Levels

When Two Decibel Values Differ by	Add the Following to the Higher Value
0 to 1 dB	3
2 to 3 dB	2
4 to 9 dB	1
10 or more dB	0

Note: To add more than two levels, start with the lowest value.

time, starting with the lowest two levels, as illustrated in Figure B2.

Although a 3-dB increase in noise level represents a doubling of sound energy, the higher level does not sound twice as loud as the lower; in fact, it is only moderately detectable by the human ear. It has been found for most sources, that a 10-dB difference in levels is needed to produce a subjective doubling of loudness. Thus, while 3 dB corresponds to a factor of two in sound *energy*, 10 dB corresponds to a factor of two in subjective *loudness*.

Propagation Characteristics

Sound from a point source attenuates according to the inverse square law: the level decreases inversely with the square of the distance. In other words, each time the distance from the noise source doubles, the sound pressure is halved, producing a 6-dB decrease in the sound signal.* Near a line source such as a highway, the attenuation approximates 3 dB per doubling of distance.

*While noise level is proportional to pressure, energy is proportional to pressure squared. Thus, while a doubling of pressure produced a 6-dB increase in the noise level, a doubling of energy produces only a 3-dB increase.

In addition to attenuation from spreading of sound waves, atmospheric effects further reduce sound. Through molecular interaction, the air absorbs a certain amount of high-frequency energy over relatively long distances. This effect can significantly influence noise signals with high frequency content, as illustrated in Figure B3. Here the typical noise level variation with distance both *with* and *without* atmospheric absorption effects is illustrated. Curve 1 represents the reduction from spreading of sound waves without atmospheric effects. Curve 2 shows how atmospheric effects increase this reduction for mid-frequency sounds. Curve 3 shows how the reduction is increased even more for high-frequency sounds.

A variety of other atmospheric phenomena, such as wind and temperature gradients, also affect the propagation of sound through the air. For sources at ground level, propagation of sound is additionally influenced by terrain and structures which may either absorb or reflect sound, depending on their surface shape and location relative to the sound source.

Frequency Characteristics

A vibrating object produces a sound wave with a characteristic frequency. Rapid fluctuations produce high-frequency sounds which are perceived subjectively as having a high pitch. The converse is true for slower fluctuations. In practice, however, a noise signal is a complex combination of frequency components produced by many different vibrational and oscillatory modes. In addition, each frequency component may have different levels and may vary as a function of time. This information is important because:

1. People with different hearing sensitivities react differently to various frequencies.

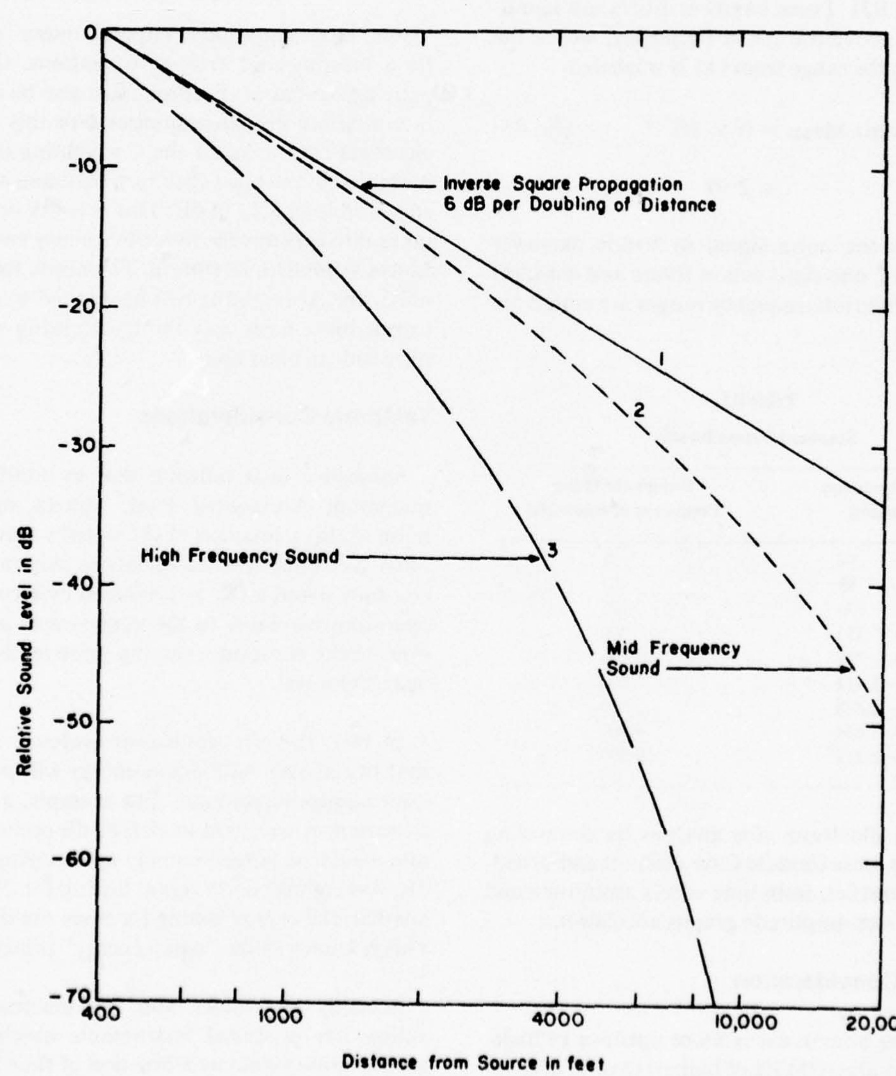


Figure B3. Typical attenuation with distance for a point source.

2. Different noise sources have different frequency characteristics.

3. Engineering solutions for reducing noise are frequency-dependent.

By using electrical filters, the noise signal can be separated into its low-, middle-, and high-frequency components via a series of eight or nine octaves. Like a musical octave on a piano keyboard, an octave in sound analysis represents the interval between a given frequency, f, and twice that frequency, 2f. The standard octave filters separate the normal audible frequency range—22 Hz to 11,200 Hz—into nine bands (Table B3). These bands or filters are identified by their geometric mean frequency, where the filter covering the range from f to 2f is labeled:

$$\text{Geometric Mean} = (f \times 2f)^{1/2} \qquad \text{[Eq B5]}$$

$$= 2^{1/2}f$$

To analyze the noise signal in bands narrower than an octave, one-third octave filters and constant bandwidth filters (all frequency ranges are equal) are used.

Table B3

Standard Octave Bands

Octave Frequency Range (Hz)	Geometric Mean Frequency of Band (Hz)
22— 44	31
44— 88	63
88— 176	125
176— 353	250
353— 707	500
707— 1,414	1,000
1,414— 2,828	2,000
2,828— 5,656	4,000
5,656—11,312	8,000

Figure B4 illustrates this analysis by comparing narrow-band noise (middle C on a piano) and broad-band noise (traffic). Both time versus amplitude and frequency versus amplitude graphs are shown.

Frequency Consideration

Because the human ear is more sensitive to high-frequency sounds (1000 Hz or higher) than to mid- or low-frequency sounds (125 Hz or lower), a better evaluation of a noise signal can be obtained by applying a weighting function to its spectrum. Figure B5 illustrates the electrical circuit placed in noise instrumentation that satisfies this requirement (A-weighting). Figure B6 illustrates the effect of applying this weighting to a typical spectrum; the resulting measure is the A-weighted sound level (AL) in decibels.

It has been found that a person's judgment of a noise's loudness correlates well with its A-weighted sound level. Thus, a noise signal with an A-weighted level of 65 dB would typically be judged louder than another noise of 60 dB when both were considered in a similar context.

For large-amplitude impulse noise emanating from blasting and artillery operations, the accompanying structural vibration must also be considered in evaluating human responses. For this source, an electrical circuit called the C-weighting (Figure B5) is applied to the blast spectrum to obtain a C-weighted sound level (CL) in dB. This network or weighting takes into account the lower-frequency energy which causes structures to vibrate. Therefore, for assessing noise, the A-weighting will be applied to all sources except blast noise and the C-weighting will be applied only to blast noise.

Temporal Considerations

Subjective tests indicate that in addition to the maximum A-weighted level, human response to noise is also a function of the signal's temporal variation. Such time-related variations may range from a constant sound level, as produced by a continuously operating machine, to the single-event aircraft fly-over, to the constantly varying noise levels perceived near highways.

In fact, there is significant evidence to indicate that two signals with equal energy will produce the same subjective response. For example, a noise with a constant A-weighted level of 85 dB occurring for 10 min would be judged equally as annoying as an 82-dB, A-weighted noise signal lasting for 20 min, i.e., one-half the energy lasting for twice the time period. This is known as the "equal energy" principle.

Recently electronics and instrumentation technology has produced instruments which can integrate a noise signal as a function of time to produce a measure of the physical energy in the noise signal. This integration results in the sound exposure level

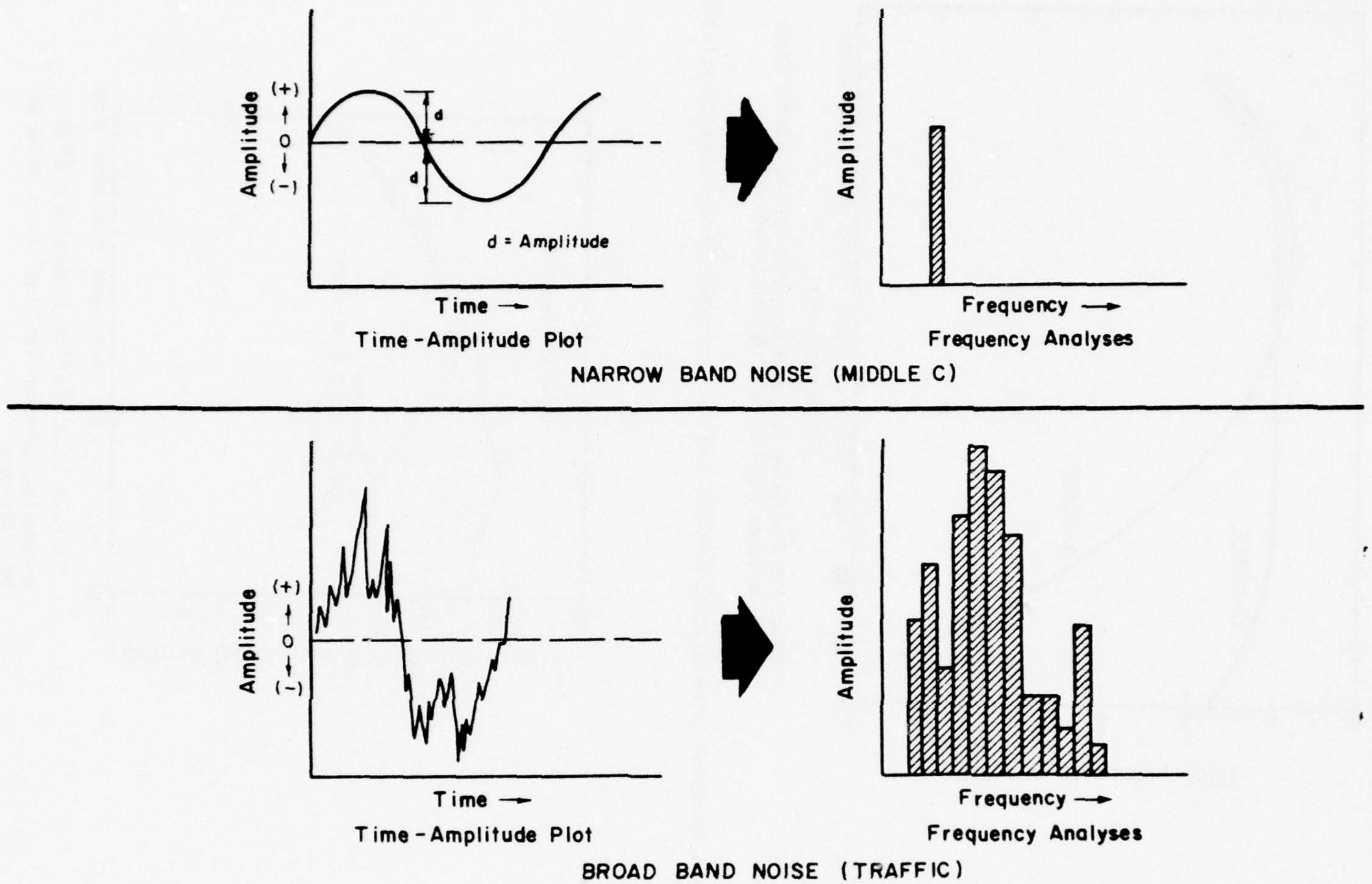
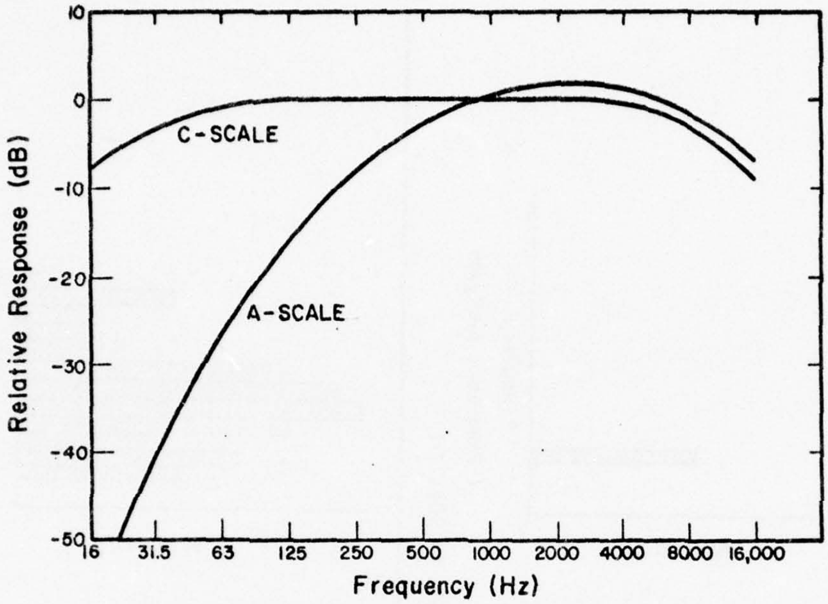
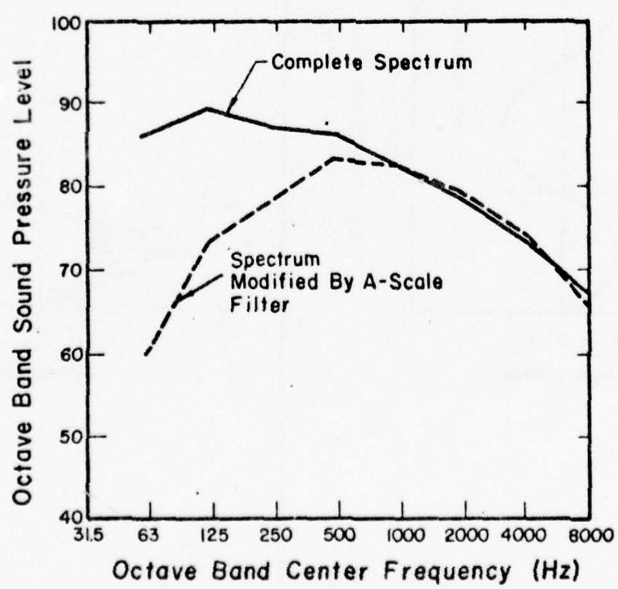


Figure B4. Typical frequency spectra.



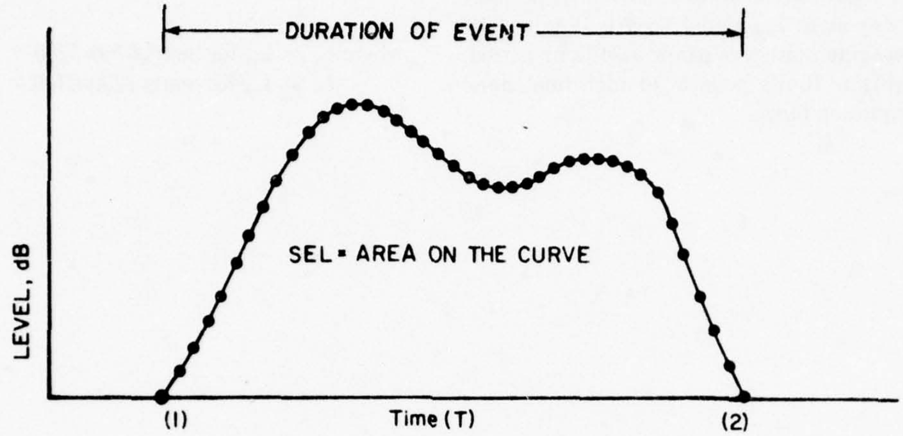
Electrical Frequency Response Specified for the A and C Scale Filter of Sound Level Meters (ANSI SI.4-1971)

Figure B5. Electrical circuit specified for the A- and C-scale network of sound-level meters (ANSI SI.4 - 1971).



Generalized Spectrum for Diesel Truck Noise At 50 ft Distance

Figure B6. The A-weighting network as applied to a typical spectrum. (From *Planning in the Noise Environment*, Draft Joint Services Planning Manual [December 1976].)



NOTE: Integration performed by summing (on an energy basis) each noise level within 10 dB of the maximum level.

Figure B7. Integration procedure for a single noise event. (From *Planning in the Noise Environment*, Draft Joint Services Planning Manual [December 1976].)

(SEL) in decibels. As an illustration, the area under the curve in Figure B7 represents the SEL of the event.

Cumulative Measures

While the A-weighted and SEL measures are theoretically appropriate for rating the noise of individual "events," in practice, the effects of noise on people and their activities result from the accumulated influence of many events occurring during a day. Thus, two cumulative measures have been developed to rate the noise environment: L_{eq} and L_{dn}.

The equivalent noise level (L_{eq}) is an energy average of the A-weighted noise levels over a selected time period. The result is a continuous noise level that is the energy equivalent of the fluctuating noise signal under consideration. L_{eq} is computed by:

$$L_{eq} = 10 \log_{10} \sum_{i=1}^{n} f_i(10)^{L_i/10} \text{ dB} \qquad \text{[Eq B6]}$$

where f_i = the percent of time the signal equals L_i
L_i = the i^{th} sound level in dB.

The typical averaging time to establish the equivalent level is 1 hour.

Example

A 24-hour time period is the period of interest and if the actual sound level had the time history shown below, what would the 24-hour equivalent level L_{eq} (24) be?

6 hours	55 dBA
12 hours	70 dBA
4 hours	75 dBA
2 hours	60 dBA

$$L_{eq} = 10 \log_{10} \sum_{n=1}^{n} f_i(10)^{L_i/10} \text{ dB} \qquad \text{[Eq B6]}$$

$$L_{eq} = 10 \log_{10}[(6/24)10^{5.5} + (12/24)10^{7}$$

$$+ (4/24)10^{7.5} + (2/24)10^{6}] \text{ dB}$$

$$L_{eq}(24) = 70 \text{ dB}.$$

Because quiet is more desirable during periods of relaxation and sleep, and because the effects of a signal are accentuated at night due to the decrease in background levels, noises occurring during the nighttime hours are usually judged to be more annoying or intrusive than those occurring during

the day. To account for this, the L_{dn} was developed. First, the day is divided into daytime (0700 to 2200 hours) and nighttime (2200 to 0700 hours) periods. Then the day-night L_{dn} sound level is obtained by energy-averaging noise levels over a 24-hour period, and applying a 10-dB penalty to nighttime noise levels. In equation form:

$$L_{dn} = 10 \log_{10} 1/24 \left[15(10)^{L_d/10} + 9(10)^{(L_n+10)/10}\right] \qquad \text{[Eq B7]}$$

where $L_d = L_{eq}$ for hours 0700-2200

$L_n = L_{eq}$ for hours 2200-0700.

APPENDIX C:

EXPLANATION OF NOISE LEVELS

This appendix summarizes the effects of various noise levels on people and will be used to quantify the impact from any activity which changes the noise environment. While Federal, state, and local regulations may establish other legal limits, the levels presented here are based on scientific knowledge and opinion regarding actual impacts and not on legal requirements. This information will help explain the meaning of the levels in terms of the criteria specified in the CEQ guidelines.

Noise Measures

Due to the wide variations in spectral and temporal characteristics of noise sources, a variety of measures and rating scales have been developed to quantify noise. While one measure may have certain advantages over another, for the purposes of the assessment it is desirable to use some common measure for all sources; therefore, only the measures listed below are used in this manual:

1. AL — A-Weighted Sound Level
2. CL — C-Weighted Sound Level
3. SEL — Sound Exposure Level
4. L_{eq} — Equivalent Noise Level
5. L_{dn} — 24-Hour Day-Night Sound Level.

The CL and AL incorporate the frequency and the SEL incorporates the temporal characteristics of the noise signal into a single numerical rating. The L_{eq} and L_{dn} represent the cumulative measures of the AL and SEL. The relationship between the five measures is illustrated in Figure C1 and discussed in Appendix B.

Environmental Attributes

As stated in the Introduction in Chapter 1, various environmental attributes are affected by Army activities. Specific attributes which may be affected by noise include:

1. Physiological maintenance
2. Sleep performance
3. Task performance
4. Aural communications
5. TV/radio communications
6. Land use
7. Community annoyance
8. Property value.

Because of a lack of conclusive data relating specific noise levels to each individual attribute, it becomes necessary to compress the list into three interrelated factors. Enough information has been gathered about these to justify establishing specific criteria.

1. Health/Welfare Effects. Interference with such activities as sleep, speech, and task performance; or attributes described by such words as "annoyance," "nuisance," and "dissatisfaction."

2. Physiological Effects. Either temporary (e.g., startle reactions and temporary hearing threshold shifts) or permanent (e.g., hearing damage or the cumulative physiological effects of prolonged sleep loss).

3. Miscellaneous Effects. Includes degradation of the environment, and effects on wildlife, land use changes, and changes in property values.

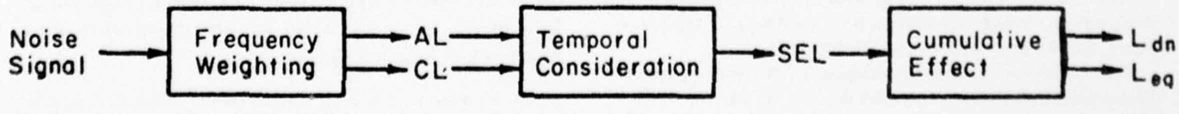


Figure C1. Relationship of noise measures.

Using speech interference and annoyance as general indicators, the U.S. Environmental Protection Agency specifies that no significant effect on health or welfare will be likely to occur if the noise environment has an L_{dn} value less than 55 dB.[25] Consequently, this level represents the primary criteria for negligible impact in residential areas for information in this manual.* As the level increases, the degree of impact will increase.

Table C1 lists specific noise criteria for other land uses. Note that these criteria are all specified in terms of the outdoor noise levels, even though the noise-sensitive activity in question is usually indoors. The average noise reduction for typical building construction was used to translate from acceptable indoor to outdoor criteria.

Although Table C1 treats all population groups alike, each community in fact will react differently to noise. Older people are more sensitive to sleep disturbances and less able to return to sleep when sleep has been interrupted. Higher-income groups are more sensitive to environmental quality and also more likely to be annoyed by noise. Fear of a noise source, such as fear of aircraft crashes, will also increase sensitivity. In addition, individuals within these groups may vary in their responses based on previous exposure and other social variables.

The results of 55 community noise histories summarized in Figure C2 illustrate the data variance. The "no reaction" response corresponds to an L_{dn} ranging from approximately 50 to 61 dB with a mean of 55 dB, while widespread complaints will occur from 60 to 70 dB with a mean of 65 dB.

Thus, to account for this variance, any criterion presented must be based upon a statistical measure of human reaction to noise. A measure of impact can therefore be either the percentage of population that feels highly annoyed about a specific level (Figure C3) or the average response of the total population (Figure C4). Note in Figure C2 that 65 dB L_{dn} produced widespread complaints; this translates to 20 percent of the population highly annoyed in Figure C3 and an average annoyance of little to moderate in Figure C4.

[25] *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With An Adequate Margin of Safety*, 550/9-74-004 (USEPA, March 1974).

*The 55-dB level is not to be construed as official Army policy. Because it is only the recommendation of the authors and subject to change, final implementation should be coordinated with the user's major command and the DA Environmental Office.

Table C1

Recommended Outdoor Criteria for Various Land Uses

These outdoor levels are established by the Committee on Hearing and Bioacoustics [CHABA]* and the Joint Services Planning Manual [JSPM].**

	CHABA		JSPM	
	L_{dn}	L_{eq}	L_{dn}	L_{eq}
Residential	55		64	
Hospital	55		64	
Hotel, Motel	60		64	
School/Outdoor Teaching Areas		55		64
Church		60		64
Office Buildings		70		69
Theater		70		69
Playground, Active Sports		70		74
Parks		60		69
Special Purpose Outdoor Areas		***		***

**Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 (Committees on Hearing and Bioacoustics, February 1977).

***Planning in the Noise Environment*, Draft Joint Services Planning Manual (December 1976).

***Outdoor amphitheaters or other critical land uses requiring special consideration should not allow new intruding noise to exceed a level 5 dB below the present L_{eq}.

In this statistical format, a much more definitive relationship can be developed between percentage of population highly annoyed and average noise level. Finally, a summary of the expected human effects for outdoor day-night average sound levels of 55, 65, and 75 dB, in terms of interference with speech communication, community reaction, annoyance, and attitude is provided in Table C2.

Physiological Effects

Whenever noise levels exceed 75 dB, there is the possibility of hearing loss and other noise-induced physiological effects. However, since a firm link between community noise and extra-auditory disease has not yet been established, the assumption must be made that protection against noise-induced hearing loss will be sufficient to protect against severe extra-auditory health effects. Thus, as the average noise level increases above 75 dB, health effects other than hearing loss may become important.[26]

[26] *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety*, 550/9-74-004 (USEPA, March 1974).

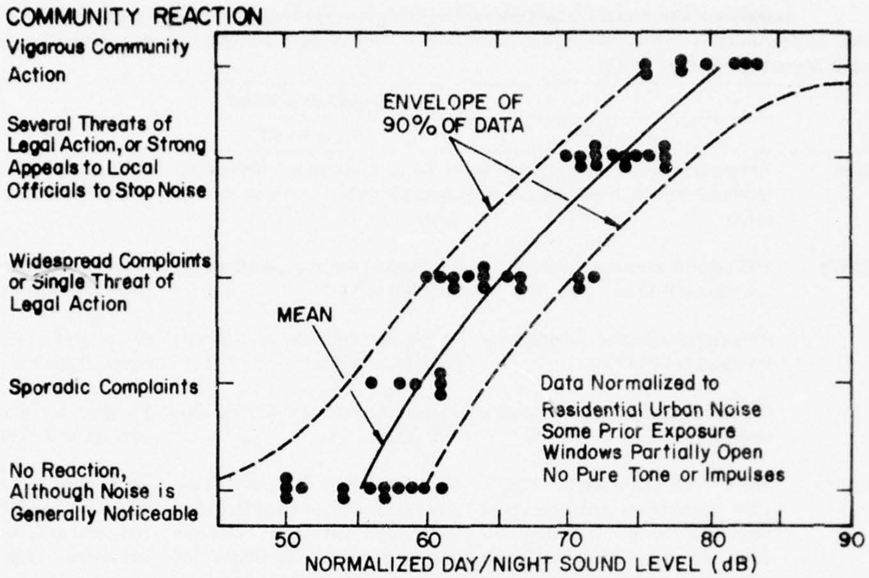


Figure C2. Community reaction to many types of intrusive noise as a function of normalized day/night sound equivalent level. (From *Community Noise*, NTID 300.3 [USEPA, 1971].)

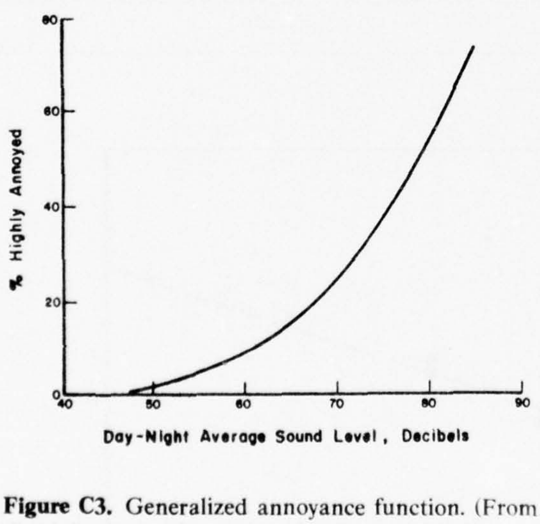


Figure C3. Generalized annoyance function. (From *Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

The definition of hearing loss currently incorporated in many hearing-damage risk criteria is obtained by a formula which uses the average hearing level at 0.5, 1, and 2 kHz. Nontheless, the ability to hear frequencies above 2 kHz is important for understanding speech and other signals. In fact, the equal discrimination point in the speech spectrum has been determined to be approximately 1.6 kHz; i.e., frequencies above 1.6 kHz are equal in importance to those below 1.6 kHz for understanding speech. As a result, protection up to at least 4 kHz is necessary to insure that all significant speech frequencies are also protected.[27]

Much hearing loss data has been collected from people with known histories of noise exposure. Comparing the levels of similar age groups with varying exposure histories reveals evidence of hearing losses.

An example of this analysis is shown in Table C3, which summarizes the expected hearing loss for daily 8-hour exposures to various noise levels over long periods of time. As indicated, hearing loss increases with both intensity of exposure and duration.

These data were used directly to generate the curves of Figure C5, which defines the criteria for hearing loss (L_{dn} greater than 75 dB) as well as those

[27]*Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety*, 550/9-74-004 (USEPA, March 1974).

Table C2

Summary of Human Effects for Outdoor Day-Night Average Sound Levels of 55, 65, and 70 dB

(From *Guidelines for Preparing Environmental Impact Statements on Noise.* Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

Type of Effect	Magnitude of Effect		
	L_{dn} = 55 dB	L_{dn} = 65 dB	L_{dn} = 75 dB
Speech—Indoors	100 percent sentence intelligibility (average) with a 5-dB margin of safety	99 percent sentence intelligibility (average) with a 4-dB margin of safety	Sentence intelligibility (average) less than 99 percent
—Outdoors	100 percent sentence intelligibility (average) at 0.35 m	100 percent sentence intelligibility (average) at 0.1 m	100 percent sentence intelligibility not possible at any distance
	99 percent sentence intelligibility (average) at 1.0 m	99 percent sentence intelligibility (average) at 0.35 m	99 percent sentence intelligibility (average) at 0.1 m
	95 percent sentence intelligibility (average) at 3.5 m	95 percent sentence intelligibility (average) at 1.2 m	95 percent sentence intelligibility (average) at 0.35 m
Average Community Reaction	None; 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other nonacoustical factors may modify this effect)	Significant; 3 dB above level of significant "complaints and threats of legal action" but at least 7 dB below "vigorous action" (attitudes and other nonacoustical factors may modify this effect)	Very severe; 13 dB above level of significant "complaints and legal action" and at least 3 dB above "vigorous action" (attitudes and other nonacoustical factors may modify this effect)
High Annoyance	5 percent, depending on attitude and other nonacoustical factors	15 percent, depending on attitude and other nonacoustical factors	37 percent, depending on attitude and other nonacoustical factors
Attitudes Toward Area	Noise essentially the least important of various factors	Noise is one of the most important adverse aspects of the community	Noise is likely to be the most important of all adverse aspects of the community

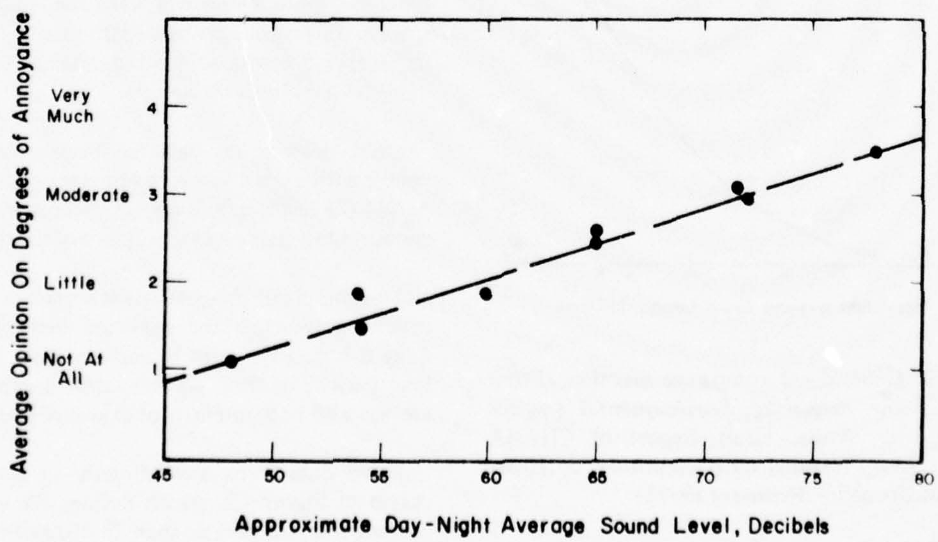
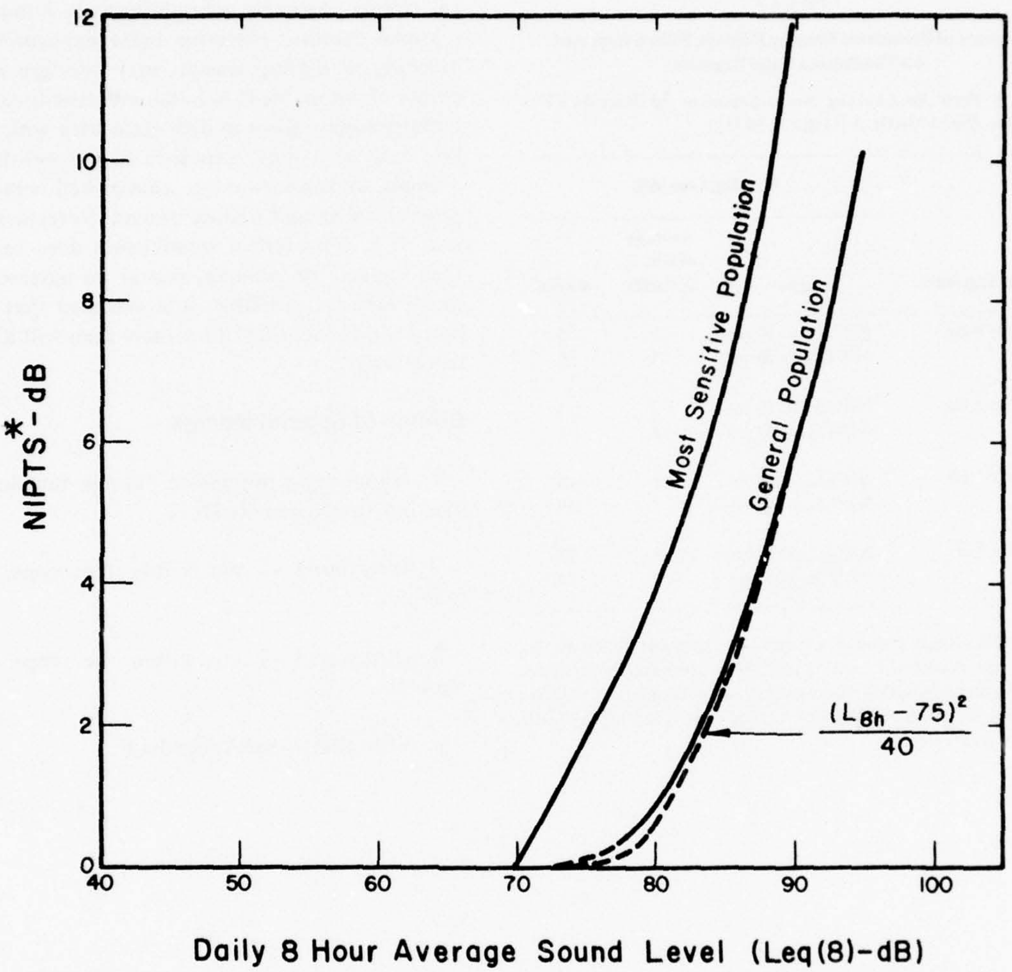


Figure C4. Average degree of annoyance as a function of L_{dn}. (From *H.M.S.O. Second Survey of Aircraft Noise Annoyance Around London [Heathrow] Airport* [1971].)



*NIPTS means noise-induced permanent threshold shift or more simply, hearing loss.

Figure C5. Criteria of hearing loss/severe health effects. (From *Guidelines for Preparing Environmental Impact Statements on Noise,* Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

for quantification of severe health effects. Since individual susceptibility to hearing loss should also be considered, it is recommended that the criteria for the most sensitive population be considered for any analysis.

Miscellaneous Effects

Even in uninhabited areas, a significant increase in noise will constitute an impact. The environment may be degraded because the increased noise affects wildlife or monuments, because it destroys the tranquility of a wilderness area, or because it makes the area unsuitable for future residential development. In each case, some natural resource is lost.

This degradation should be quantified using the generalized annoyance function in Figure C2, even though there are no actual health or welfare effects. In this instance, the percentage of population highly annoyed is considered a measure of the environmental degradation.

Noise generally affects animals in the same manner as humans—hearing loss, masking of communication, and behavioral nonauditory physiologi-

Table C3

Summary of Permanent Hearing Damage Effects Expected for Continuous Noise Exposure

(From *A Basis for Limiting Noise Exposure for Hearing Conservation*, 550/9-73-001-A [USEPA, 1973].)

	Hearing Loss (dB)		
Type of Exposure	**Type**	**Average of 0.5, 1, 2, 4 kHz**	**4 kHz**
75 dB for 8 Hr	$NIPTS_{90}^{*}$ at 10 yrs	1	5
	$NIPTS_{90}$ at 40 yrs	2	6
80 dB for 8 Hr	$NIPTS_{90}$ at 10 yrs	3	9
	$NIPTS_{90}$ at 40 yrs	4	11
85 dB for 8 Hr	$NIPTS_{90}$ at 10 yrs	6	16
	$NIPTS_{90}$ at 40 yrs	7	19
90 dB for 8 Hr	$NIPTS_{90}$ at 10 yrs	12	28
	$NIPTS_{90}$ at 40 yrs	9	24

*NIPTS (Noise Induced Permanent Threshold Shift) is the permanent change in hearing threshold attributable to noise. $NIPTS_{90}$ represents data from the 90th percentile point of population (i.e., 90 percent of the people have better hearing while 10 percent have worse).

cal effects. Animals are additionally impacted by seasonal factors: excessive noise exposure during breeding or mating seasons may interfere with the ability of parent birds to hatch and rear their young. Unfortunately, there is little data with which to relate long-term noise exposure to the well-being of animals, and in turn relate animal well-being to the general health and welfare of man. Nevertheless, the lack of a cause/effect relationship does not mean that impacts on animals should be ignored. Until more data are available, it is assumed that the exposure level identified to protect man will also protect animals.

Effects of Special Noises

1. High-energy impulsive sounds (artillery and blasting) (see Appendix D).

2. Infrasound — not within the scope of this manual.

3. Ultrasound — not within the scope of this manual.

4. *Vibration* — see Appendix F.

APPENDIX D:

PREDICTION OF SPECIFIC CONTOURS

This appendix describes the use of analytic models to generate contours for the Army-related noise sources listed in Table D1. For each model, background information is provided about the noise source, followed by manual procedures for estimating the noise exposure and drawing simplified equal noise contours. Where computer-generated contours are available, information concerning the necessary input data is provided. Finally, examples illustrate use of the model. These models do not account for shielding effects of landforms, buildings, or other barriers located between one source and observer. In addition, attenuation due to atmospheric absorption is not considered. Only the unobstructed, pure contour is presented. Finally, for all sources except blast noise, the A-weighted sound level will be used as the descriptor. For blast noise, the C-weighted sound level will be applied.

Transportation Noise—Railroad Operations

There are two distinct types of railroad noise: noise from line operations involving the movement of a train from one point to another, and noise from yard/siding operations involving loading, switching, storage, and maintenance. Only line noise is applicable to Army facilities.

Railroad line noise has an engine component and a car component. The engine component includes exhaust and casing noises. The former increases with horsepower, while the latter depends on both horsepower ratings and RPM. Car noise is created by the interaction of steel wheels and rails, and increases markedly with train speed. In addition, there is wheel "squeal" when a train traverses a tight curve, and impact noise when wheels pass over a joint, frog, or signal junction. The train horn represents another significant source of noise.

Table D1

Organization of Appendix D

Noise Source	Pages
Ground Transportation	
Railway	73
Highway	75
Combat Vehicle Maneuver	83
Construction	83
Aircraft Operations	
Rotary-Wing	85
Fixed-Wing	98
Ground Operations	98
Impulse Noise	
Blast/Artillery	101
Pistol Range	104

The total noise exposure from line operations is a function of both the noise level and the duration of passby, which in turn depends on train speed and length.

Evaluation Procedure

To evaluate line operations, the following procedures have been developed, based on several simplifying assumptions concerning the type, length, and speed of the most commonly encountered trains. The analysis is valid for operations on level grade, with no shielding between the train and receiver.

1. Determine the SEL at the desired distance for typical train operations from Figure D1.

2. For each operation, determine L_{eq} or L_{dn} using:

$$L_{eq} = \text{SEL} + 10 \log_{10} N - 35.6 \qquad \text{[Eq D1]}$$

$$L_{dn} = \text{SEL} + 10 \log_{10} (N_d + 10\, N_n) - 49.4 \qquad \text{[Eq D2]}$$

where N = number of operations within a 1-hour period
N_d = number of daytime [0700-2200] operations
N_n = number of nighttime [2200-0700] operations.

3. Correct L_{dn} or L_{eq} levels according to the conditions in Table D2. In the case of multiple variables, only the larger value should be used.

Table D2

Adjustments to L_{dn} or L_{eq} Contours for Railroads

(From Unpublished notes from Report 193A, Richard K. Miller and Associates.)

Variable	Adjustment dB
Low-speed classified jointed track	−4
Presence of switching frogs or grade crossing	+4
Tight radius curve less than 600 ft (180 m)	+4
Presence of light steel trestle bridge work	+14
Presence of heavy steel trestle bridge work	+5

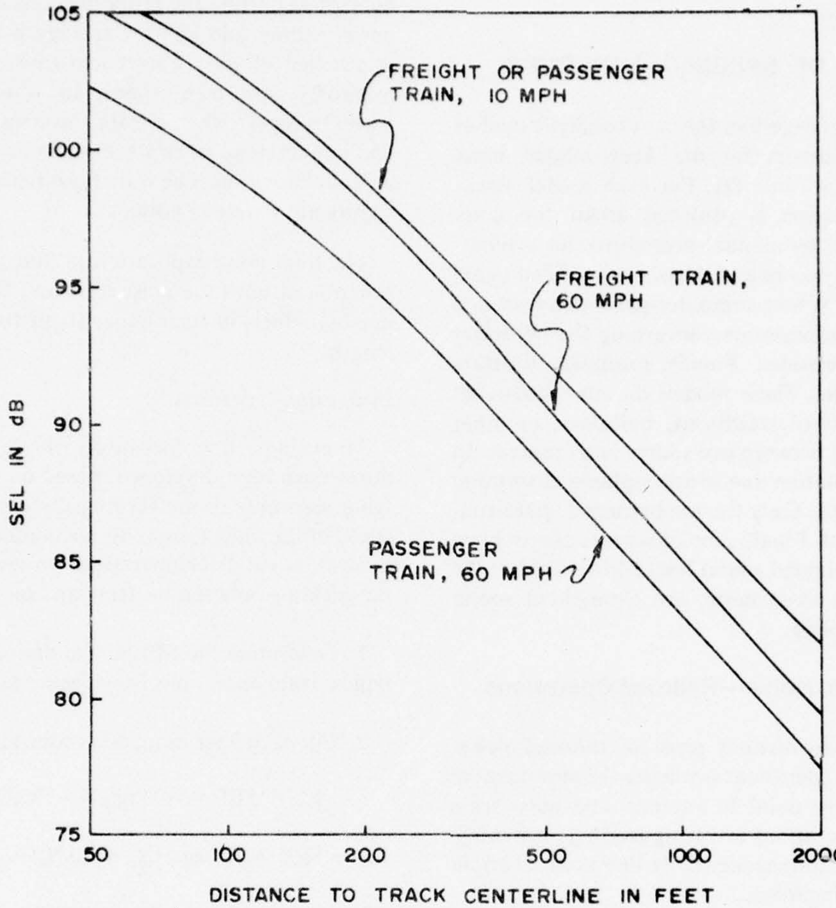


Figure D1. Variation of SEL with distance for trains. (From *Planning in the Noise Environment,* Draft Joint Services Planning Manual [December 1976].)

4. If several trains use a particular track, logarithmically add L_{dn} or L_{eq} values for each.

5. Adjust values to different distances by using Figure D1 for other distances and repeating steps 1 through 4.

6. Plot noise contours by drawing lines at appropriate distances along and parallel to the rails.

Example

Ten daytime and one nighttime freight operations and two daytime passenger operations occur over a segment of welded mainline track. One section of track contains a radius of less than 600 ft (180 m). Find L_{dn} at 500 ft (150 m).

Step 1. Determine SEL at 500 ft (150 m) for each operation using Figure D1.

SEL = 90 for freight

SEL = 88 for passenger

Step 2. Determine L_{dn} for each operation using Eq D2.

$$L_{dn} = \text{SEL} + 10 \log_{10}(N_d + 10\,N_n) - 49.4 \quad \text{[Eq D2]}$$

$$L_{dn} = 90 + \log_{10}(10 + 10(1)) - 49.4$$

$$= 53.6 \text{ for freight.}$$

$$L_{dn} = 88 + 10 \log_{10}(2 + 10(0)) = 49.4$$

$$= 41.6 \text{ for passenger.}$$

Step 3. Make corrections from Table D2 for a radius less than 600 ft (180 m).

$L_{dn} = 53.6 + 4 = 57.6$ for freight

$L_{dn} = 41.6 + 4 = 45.6$ for passenger

Step 4. Combine L_{dn} values from each operation.

$L_{dn} = 57.6 \oplus 45.6 = 57.6$ dB.

Transportation Noise—Highway[28]

Highway noise caused by private and combat vehicles is best evaluated by dividing private vehicles into automobile and truck classes, and combat vehicles into transport and weapons classes. The total noise exposure can then be determined from the volume flow and the average speed for each vehicle class.

The primary noise source of an automobile is tire-roadway interaction. The levels increase with speed, as illustrated by Figure D2. Trucks, because of their source characteristics, should be subdivided into three classes: light, medium, and heavy. Light trucks are two-axle, four-wheeled vehicles (e.g., panel and pickup) whose noise levels and characteristics are similar to those of automobiles. Medium trucks are two-axle, six-wheeled vehicles and are typically gasoline-powered. Although their noise characteristics are similar to those of automobiles, medium trucks are usually 10 dB noisier for the same flow and speed. The tire-roadway interaction, a major source for all these vehicles, occurs at ground level and is a function of speed. Heavy trucks are diesel-powered, have three or more axles, and contain many noise-creating mechanisms, i.e., tires, exhaust, engine, and gears. The major source—exhaust noise—occurs at the stack opening which is normally located 8 ft (2.4 m) above the ground and is not generally dependent on road speed.

Combat vehicles can be divided into two classes: troop transport and mobile weapon carriers. Transport vehicles are either wheeled or a combination of wheeled and tracked; weapons vehicles are usually tracked. Measurements have shown that all combat vehicles are up to 10 dB noisier than heavy trucks. The major noise sources are the engine, drive gears, and track, with track noise dominant in those vehicles so equipped.

The total noise exposure from a highway is a function of the hourly volume flow and the average speed (mph) for each vehicle class. In addition, various roadway factors such as grade, surface, and configuration will affect the levels.

Because roadways are not infinitely long and straight, they are often evaluated in sections based on physical conditions. For example, dividing a roadway whose surface is rough over half its length into a smooth section and a rough section would improve the accuracy of the noise estimation.

Evaluation Procedure

A computer is usually required to accurately assess detail traffic and roadway variables in the derivation of contours; however, for an assessment, the manual approach presented here is adequate. These steps are illustrated by the example on page 77.

1. Prepare the matrix form (Figure D3) for each segment of roadway.

2. Determine the average speed and hourly volume of vehicles in each class. Note that the automobile class consists of the total:

$$\text{Automobiles} = A + Lt + 10\,Mt \qquad \text{[Eq D3]}$$

where A = number of automobiles/hour

Lt = number of light trucks/hour

Mt = number of medium trucks/hour.

When the percentage of trucks exceeds 4 percent, the noise impact of automobiles can be neglected, since their level is more than 10 dB less than that of trucks. Whenver data on mixture of traffic is not available, assume 3.5 percent heavy trucks and 96.5 percent automobiles.

3. Use Figures D4 and D5 to determine the hourly L_{eq} at the desired distance for each vehicle class in each segment. These figures are for a flat, infinitely long roadway with no barriers. Their use will be detailed in the example which follows.

[28] *Planning in the Noise Environment*, Draft Joint Services Planning Manual (December 1976).

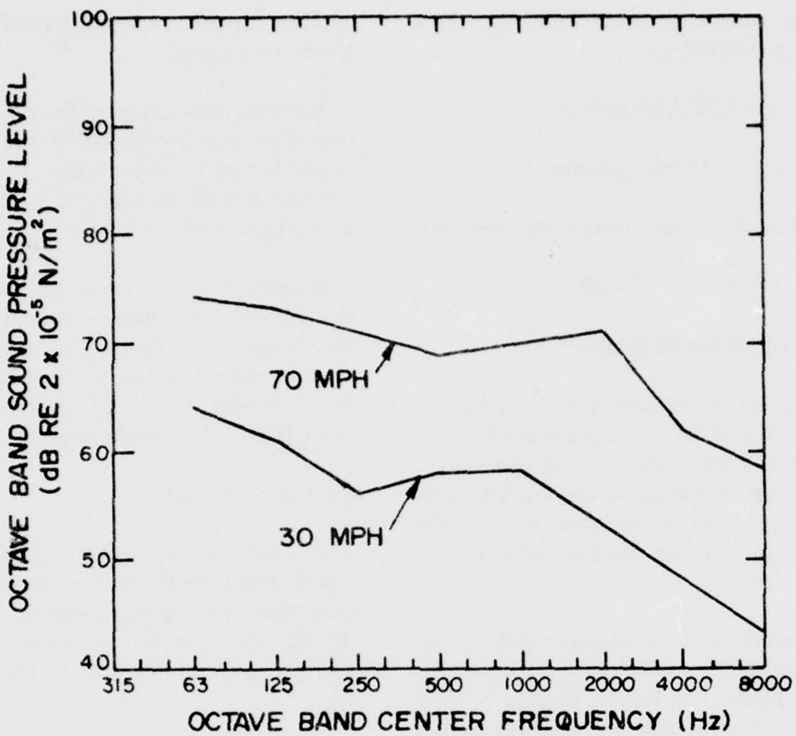


Figure D2. Dependence of automobile noise emissions on speed. (From *Planning in the Noise Environment*, Draft Joint Services Planning Manual [December 1976].)

4. Make the following adjustments to the L_{eq} of each vehicle class in each segment.

a. Subtract the value determined in Figure D6 based on the angle of observation (θ).

b. Add 5 dB to the L_{eq} of all wheeled vehicles where the roadway is unusually rough, i.e., broken pavement or large voids and grooves in the surface.

c. On segments with gradients, add to the L_{eq} of transport and heavy trucks the adjustments from Table D3.

5. Sum the adjustments to obtain an L_{eq} value for each vehicle class.

6. Sum the L_{eq} for each vehicle class to obtain L_{eq} for each segment.

7. Sum the L_{eq} for each segment to obtain an L_{eq} for the entire highway.

8. Convert from L_{eq} to L_{dn} using Table D4.

Table D3

Adjustment in dB for Roadway Gradient

(From *Planning in the Noise Environment*, Draft Joint Services Planning Manual [December 1976].)

	Average Speed (mph)		
Percent Grade	**<20**	**20-35**	**>35**
1	4	3	2
2	5	4	3
3	6	5	4
4	7	6	5
5	8	7	6

Table D4

Adjustment of L_{eq} to L_{dn}

(From *Planning in the Noise Environment*, Draft Joint Services Planning Manual [December 1976].)

% Day Operations	Add to L_{eq}
62.5	3
75	2
85	1
90	0
95	−1
100	−3

	HEAVY TRUCKS	AUTOMOBILES	TRANSPORT VEHICLES	WEAPONS VEHICLES
AVERAGE SPEED (MPH)				
HOURLY VOLUME				
L_{eq}				
SEGMENT ADJ				
GRADIENT ADJ				
ROUGHNESS ADJ				
ADJUSTED L_{eq}				
SEGMENT L_{eq}				

Figure D3. Matrix used in highway noise analysis.

9. To obtain contours, the roadway must be considered as an infinitely long single segment. Within this constraint, the L_{eq} or L_{dn} values can be adjusted for other distances (Y) by:

$$\text{Adjustment} = -15 \log_{10} Y/X \qquad \text{[Eq D4]}$$

Contours can then be drawn at appropriate distances from the center line, parallel to the sections of roadway under study.

Example

Find the L_{dn} value at a site located 200 ft (60 m) from a highway having the following operational characteristics:

1. Vehicle flow—20 heavy trucks per hour @ 20 mph (8.9 m/sec)
   —2000 automobiles per hour @ 30 mph (13.4 m/sec)
   —50 medium trucks per hour @ 30 mph (13.4 m/sec)

2. Fifteen percent of vehicle flow occurs at night

3. Half of road is flat; half has 2 percent grade

4. Change of grade occurs directly opposite site (Figure D7).

Step 1. Create a matrix for each segment (Figure D8).

Step 2. Fill in rows 1 and 2 of each segment matrix using operational information and Eq D3.

Step 3. Using Figure D9, determine the L_{eq} at 200 ft (60 m) for each class of vehicle.

a. From the pivot point in Figure D9, draw a line through the average speed (20 mph [8.9 m/sec] for trucks and 30 mph [13.4 m/sec] for automobiles) and extend it until line A is intersected.

b. From this intersection, draw another line to the appropriate vehicle volume (20 for heavy trucks and 2500 for automobiles). Circle each intersection with line B.

c. From line B, draw a line to the appropriate

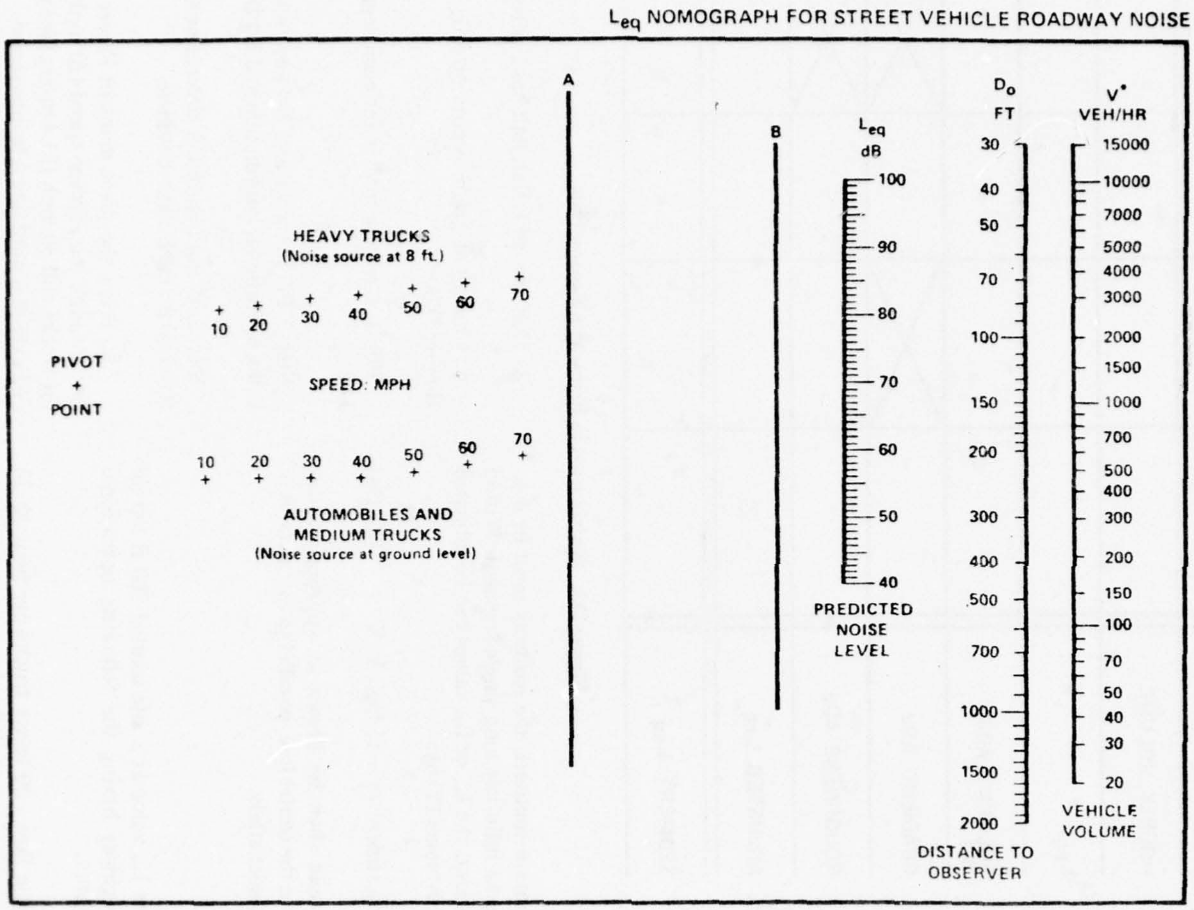


Figure D4. Nomograph for determining L_{eq} levels from private vehicles. (From *Planning in the Noise Environment,* Draft Joint Services Planning Manual [December 1976].)

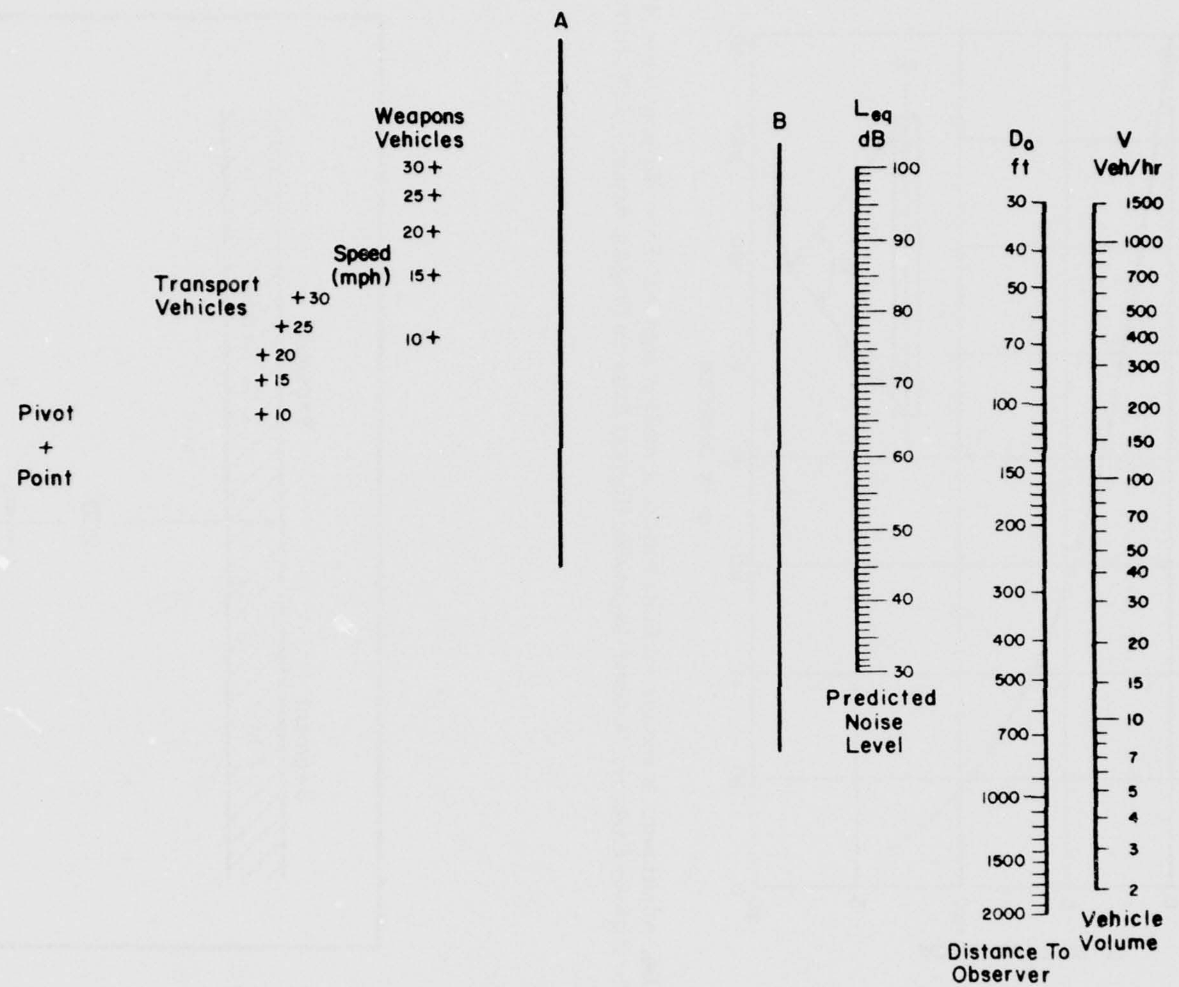


Figure D5. Nomograph for determining L_{eq} levels from combat vehicles. (From *Planning ~~in the Noise~~ Environment.* Draft Joint Services Planning Manual [December 1976].)

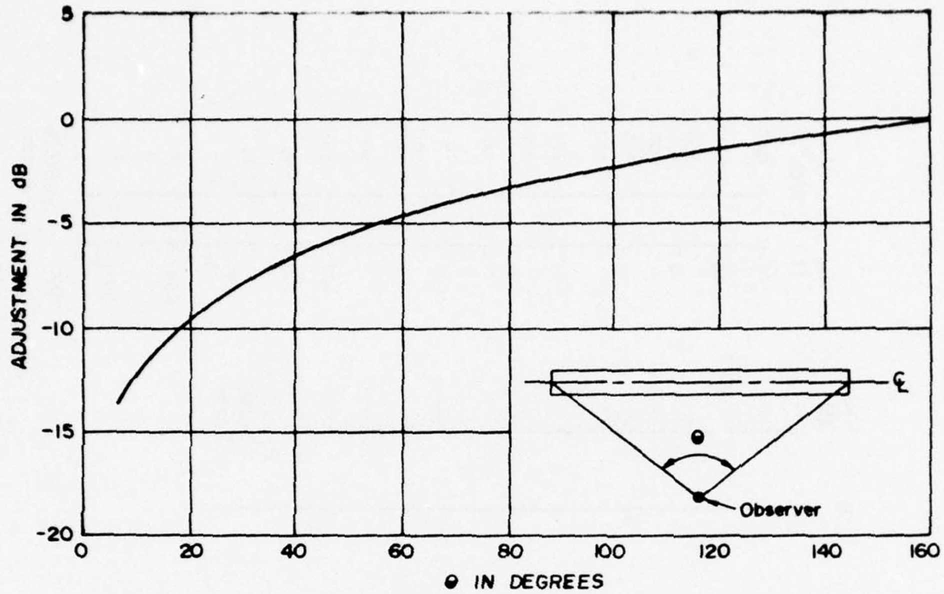


Figure D6. Adjustments to account for finite lengths of roadway segment. (From *Highway Noise, A Design Guide for Highway Engineers,* National Cooperative Highway Research Program Report 117 [NCHRP, 1971].)

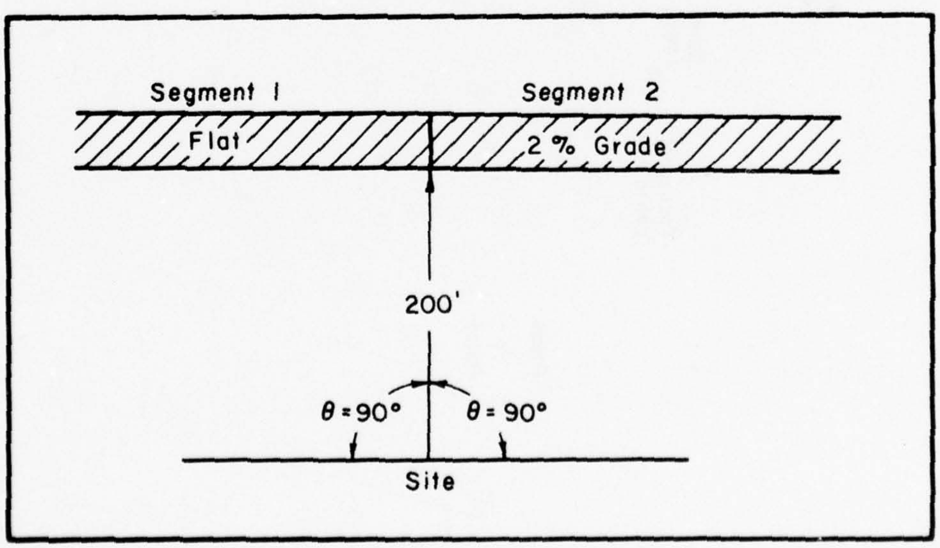


Figure D7. Layout of example problem.

Segment # 1

Operational		Heavy Trucks	Automobiles
Row 1	Average speed (mph)	20	30
Row 2	Peak hour volume (vph)	25	2500
Row 3	L_{eq} in dB	64	59
Row 4	Segment adj; $\theta = 90°$	−3	−3
Row 5	Gradient adj; Grade = 2%	+4	—
Row 6	Barrier adj	0	0
Row 7	Roughness adj	0	0
Row 8	Adjusted L_{eq} in dB	65	56
Row 9	Segment L_{eq} in dB	66	

Segment # 2

Operational		Heavy Trucks	Automobiles
Row 1	Average speed (mph)	20	30
Row 2	Peak hour volume (vph)	25	2500
Row 3	L_{eq} in dB	64	59
Row 4	Segment adj; $\theta = 90°$	−3	−3
Row 5	Gradient adj; Grade = 0%	0	—
Row 6	Barrier adj	0	0
Row 7	Roughness adj	0	0
Row 8	Adjusted L_{eq} in dB	61	56
Row 9	Segment L_{eq} in dB	62	

Figure D8. Highway noise worksheet.

distance between the observer and the highway (200 ft [60 m] in this case).

d. At the intersection of this line and the L_{eq} scale, read the L_{eq} value (64 for heavy trucks and 59 for automobiles and medium trucks).

e. Fill in row 3 of each segment matrix with these values.

Step 4. Fill in rows 4 through 7 of each matrix with the following adjustments.

a. Place −3 dB in row 4 of both segments for angle adjustment (from Figure D6, $\theta = 90°$).

b. Place +4 dB in row 5 of 2nd segment for grade adjustment (from Table D3, grade = 2 percent; speed = 20-35 mph).

Step 5. Compute row 8 of each matrix by summing rows 3 through 7.

Step 6. Compute row 9 of each segment by summing the L_{eq} from each vehicle class.

Step 7. Determine L_{eq} from both segments
Total L_{eq} = 66 + 62 = 67

Step 8. Convert L_{eq} to L_{dn} with the adjustments in Table D4.

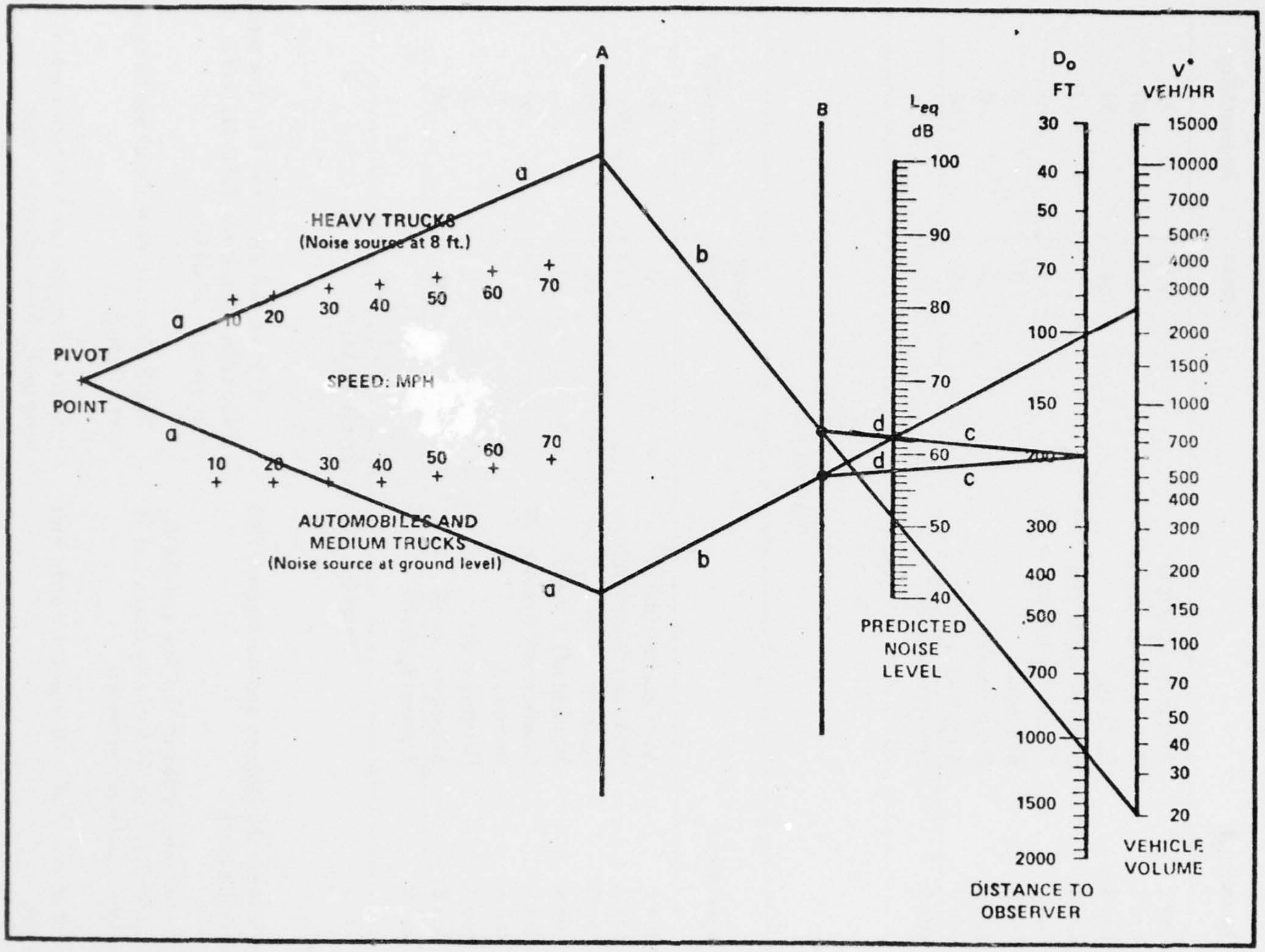


Figure D9. Example nomograph for determining L_{eq} levels from private vehicles.

$$L_{dn} = L_{eq} + \text{adj} = 67 + 1 = 68$$

Combat Vehicle Maneuvers

Whenever maneuvers are being held in an area, the complexity of the noise problem is increased because the roadway is not fixed. Since a predictive procedure has not yet been developed for this source, the recommendation would be to measure the noise levels from several locations and then use the following steps to calculate L_{dn} or L_{eq}.

1. Outline area of operation and pick four measuring points in different locations, but a fixed distance from the perimeter of the area (Figure D10).

2. Measure SEL value of operation at each location for 1 hour during a period of heavy usage using procedures outlined in Appendix E.

3. Calculate average SEL using

$$\text{SEL} = \log_{10} \frac{1}{n} \sum_{i=1}^{n} 10^{\text{SEL}_i} \qquad \text{[Eq D5]}$$

where SEL_i = SEL at the i^{th} location

n = number of locations.

4. Use Eqs D6 and D7 to find L_{dn} or L_{eq}

$$L_{eq} = \text{SEL} + 10 \log_{10} D - 35.6 \qquad \text{[Eq D6]}$$

$$L_{dn} = \text{SEL} + 10 \log_{10} (D_d + 10\, D_n) - 49.4 \quad \text{[Eq D7]}$$

where D = duration of event in seconds during 1-hour measurement period

D_d = duration of event in daytime [0700-2200] in seconds

D_n = duration of event in nighttime [0700-2200] in seconds.

5. Make distance adjustment using

$$\text{ADJ} = -15 \log_{10} Y/X \qquad \text{[Eq D8]}$$

where X = distance of microphone from boundary

Y = other distances of interest.

6. Draw contours by plotting L_{dn} or L_{eq} values at various distances Y from the boundary (Figure D10).

Construction

Noise from construction operations is different from other major sources for two reasons. First, it is caused by many types of equipment. Second, the resultant adverse effects (annoyance, speech and sleep interference, etc.) will be temporary because the operation is relatively temporary. In addition, since construction usually occurs during the day, there is a minimum of sleep interference. Thus, to develop an evaluation procedure for construction noise, the time and detail involved must be weighed carefully against its unique and temporary nature.

The basic unit of construction activity is the construction site, which exists in both time and space. The time dimension consists of the following five phases which change the character of the site's output as work progresses: ground clearing, excavation, foundation, erection, and finishing. Each phase is characterized by certain types of equipment, each of which has its own random operation. Thus, to accurately compute the noise exposure from a site, the following information must be integrated with each piece of equipment during each phase:

1. The time-varying history of the noise emitted by the equipment

2. The time-varying history of the location of the equipment

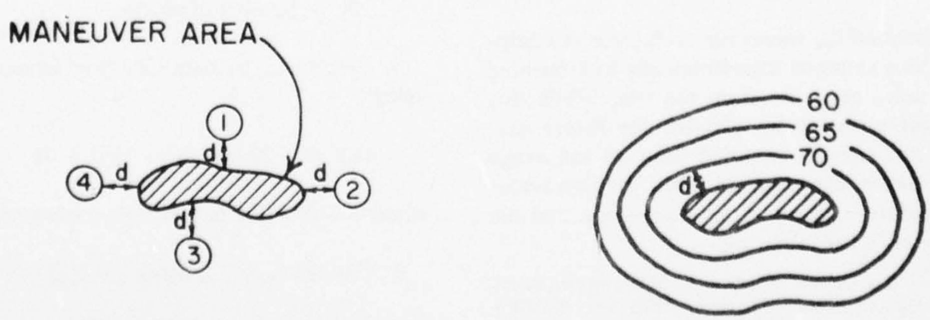


Figure D10. Location of measurement points and plotting of contours.

Table D5

Example of Construction Usage Factor Technique

Equipment Type	Lat 50′	Ui for Construction (1000 hrs) Clearing 100 hrs	Excavation 200 hrs	Foundation 400 hrs	Erection 200 hrs	Finishing 100 hrs	Σ Ui Ti	L_{eq} at 50 ft (15 m) (from Eq D9)
Air compressor	(81)*	—	1.0	0.4	0.4	0.4	480	77.8
Backhoe	(85)	0.04	0.16	0.4	—	0.04	200	78.0
Concrete mixer	(85)	—	—	0.4	0.16	0.16	208	78.2
Crane, mobile	(83)	—	—	—	0.08	0.04	20	66.0
Dozer	(87)	0.2	0.4	—	—	0.04	104	77.2
Generator	(78)	0.4	0.4	—	—	—	120	68.8
Grader	(85)	0.05	—	—	—	0.02	7	63.5
						Total L_{eq} at Site*		84.1

*L_{eq} at site equals logarithmic addition of L_{eq} values of all the individual pieces of equipment on the site.

Ideally, these factors should be measured directly. However, since construction is dynamic in nature, by the time one phase could be measured and analyzed, it would be well under way or even completed. Thus, the process of evaluating alternatives or mitigation techniques would be wasted. However, by making some assumptions, the evaluation process can be reduced to the form illustrated in Table D5.[29]

For this method, each source is assumed to be the same distance from the observer; the total L_{eq} of that source for the entire operation is calculated by:

$$L_{eq} = \overline{L} + 10 \log_{10} \frac{1}{T} \sum_{i=1}^{5} Ui \cdot Ti$$

where Ui = usage factor of i^{th} phase (Table D5)
Ti = total time (hours) of i^{th} phase
T = total time (hours) required for entire construction project
$\overline{L}$ = average noise level during actual operating cycle.

The individual L_{eq} values for each piece of equipment are then summed logarithmically to determine the total noise exposure from the site. While this method will probably be adopted for future use, there are not enough recorded data on the usage factor to make its use practical. Thus, the best evaluation procedure in terms of time, accuracy, and the state of the art is the following.

[29] *Noise from Construction Equipment and Operations, Building Equipment and Home Appliances*, NTID 300.1 (USEPA, 1971).

Evaluation Procedure

1. Using Table D6, determine the L_{eq} from the site for each phase of construction. This is based on:

a. The basic type of construction

b. Anticipated usage of all pertinent equipment or minimum required equipment at the site.

2. Determine L_{eq} from the site for the entire operation using Eq D9.

$$L_{eq} = 10 \log_{10} \frac{1}{T} \sum_{i=1}^{N} T_i (10)^{L_i/10} \qquad \text{[Eq D9]}$$

where L_i = L_{eq} for the i^{th} phase from Table D6
T_i = total time duration i^{th} phase from Table D6
T = total time of operation from the time initial phase (i = 1) begins until the final phase (i = N) begins
N = number of phases.

3. Correct L_{eq} to distance (X) of interest from site using:

$$ADJ = -20 \log_{10}[X + 250] + 48 \qquad \text{[Eq D10]}$$

where X is distance in feet from the boundary.

4. Change L_{eq} to L_{dn} using Table D7.

5. Draw L_{eq} or L_{dn} contours around the site.

Table D6

Equivalent Sound Levels in dBA for Various Construction Activities*

(From unpublished notes from Report 193A, Richard K. Miller and Associates.)

Type	Domestic Housing		Office Building Hotel Hospital		Roads and Highways, Sewers and Trenches		Commercial Industrial Structures	
Phase	**I**	**II**	**I**	**II**	**I**	**II**	**I**	**II**
1. Ground Clearing	83	83	84	84	84	84	84	83
2. Excavation	88	75	89	79	88	78	89	71
3. Foundations	81	81	78	78	88	88	77	77
4. Erection	81	65	87	75	79	78	84	72
5. Finishing	88	72	89	75	84	84	89	74

I All pertinent equipment present at site.
II Minimum required equipment at site.

*This table presents typical ranges of noise levels calculated for four types of construction with either all or minimum equipment at the site. The levels are categorized into the five phases discussed in the text. The noise levels have been derived using the following assumptions: (1) each item of equipment operates randomly, (2) the noisiest piece of equipment is located 50 ft (15 m) from the site boundary, and (3) all other equipment is located 200 ft (60 m) from the site boundary.

Example

A construction operation consists of ground clearing and excavation for domestic housing. If the total scheduled time from start to finish is 3 months or 2160 hours, compute the L_{dn} at a site 200 ft (60 m) from the project. Assume the following conditions:

1. All pertinent equipment will be used
2. All activity occurs during the day (0700-2200)
3. Ground clearing is scheduled for 300 hours
4. Excavation is scheduled for 1000 hours.

Step 1. From Table D6, determine L_{eq} at the boundary of the construction site for each phase:

Excavation - 88 dB

Ground clearing - 83 dB

Step 2. Determine L_{eq} for the total operation using Eq D9.

$$L_{eq} = 10 \log_{10} \frac{1}{T} \sum_{i=1}^{n} T_i (10)^{L_i/10} \qquad \text{[Eq D9]}$$

Table D7

Adjustment for L_{eq} to L_{dn} (Construction)

% Night Operations	Add to L_{eq}
0	0
5	1.5
10	3
15	4
25	5
37.5	6
50	7.5
75	9
100	10

$$= 10 \log_{10} 1/2160\ [300(10)^{8.3} + 1000(10)^{8.8}]$$

$$= 85 \text{ dB}$$

Step 3. Correct L_{eq} to desired distance from site using Eq D10.

$$\text{ADJ} = -20 \log_{10} [X + 250] + 48 \qquad \text{[Eq D10]}$$

$$\text{ADJ} = -20 \log_{10}[450] + 48$$

$$= -5$$

$$L_{eq} = 85 - 5 = 80 \text{ dB}$$

Step 4. Convert to L_{dn}. Since all activity occurs during the day, L_{dn} = 80 dB.

Rotary-Wing Aircraft

Evaluation of rotary-wing aircraft has previously been combined with general airport operations; however, its unique characteristics and extensive Army usage have led to the development of prediction models. As a result, it can now be evaluated as an autonomous source.

With rotary-wing aircraft, both the engine and rotary system are principal noise sources consisting of five major components: rotor blade slap, tail rotor rotational noise, main rotor broad band and rotational noise, turbine engine noise, and transmission noise.

The dominant noise consists of air flow past the helicopter blade (rotor blade slap). In addition, blade slap is caused both by the cutting of one blade's tip vortices by another blade and by transient shock. Blade slap is a distinctive, low-frequency

throbbing sound which increases during descent, maneuvering, and high-speed cruise operations.

Evaluation Procedure

The prediction procedure for helicopters is a modification of CERL publication N-10.[30] Generating noise contours involves six steps:

1. Laying out corridors and zones
2. Tabulating number of operations
3. Description of altitude profiles
4. Separation of corridors and zones
5. Calculations of noise impact
6. Mapping of contours.

The example problem below details the procedure. The 70 L_{dn} contour is the level of interest.

Example[31]

Figure D11 is a sketch of a hypothetical base. The parallel taxiway handles approximately one-fourth of the rotary-wing traffic and is used to practice "touch-and-go." Operational helipads 1, 2, and 3 are used for the rest of the helicopter flights. There are two training areas south of the base: Field Training Exercise (FTX) and Nap of the Earth (NOE) field areas. To reach them, aircraft follow the highway west of the base and the railroad tracks, respectively. Departures are usually straight-out, and approaches use the south pattern from the helipad to get to the corridors.

Step 1. Lay Out Corridors and Zones for All Operations. First, place aircraft that follow a particular route inside a corridor. Whenever it is not possible to draw corridors due to the somewhat random nature of rotary-wing flight, zones should be drawn to represent land overflown by most of the aircraft performing the activity.

Activity around airfields is treated as a normal corridor. If altitude information is not available, assume an average altitude of 300 ft (91 m).

If the average daily number of operations for any activity (training, VIP transport, medical assistance) is less than 10, no corridors or zones should be drawn.

Figure D12 shows the corridors and zones on the example base. Zones are drawn around the FTX and NOE areas and around the helipad patterns. Corridors are drawn for the "touch-and-go" operations and the flight routes to the FTX and NOE areas.

Step 2. Record the Number of Daily Operations for Each Corridor and Zone. An operation is defined as a takeoff or landing in a pattern or a fly-by in a corridor. A "touch-and-go" is counted as two operations.

Figure D13 shows these operations for each zone and corridor. There are 70 operations along the highway route to the FTX area; 35 are departures and 35 are arrivals. The NOE route along the railroad tracks handles 160 average daily operations—80 arrivals and 80 departures. The airfield handles 160 + 70, or 230 operations.

Step 3. Describe Average Altitude Profiles in Each Corridor. This information can be obtained from personnel familiar with the airfield and its operation. As illustrated in Figure D14, rotary-wing aircraft cruise at 1500 ft (457 m) above ground level (AGL) along the highway route and 1000 ft (305 m) along most of the railroad route. Transition points (change from ascent/descent to level flight) are indicated with bars perpendicular to the corridors.

Step 4. Separate Corridors and Zones. Usually, the number of sections should be limited to 15 or less. Reductions can be accomplished by simplifying altitude profiles or by grouping nearby corridors. These sections are illustrated in Figure D15 and listed in Table D8.

Step 5. Calculate Noise Impact. The impact from each corridor and zone should be analyzed in the following order:

a. Corridors of constant altitude (Sections 5 and 6 in Table D8)

b. Corridors of ascent and descent (Sections 3, 4, and 7 in Table D8)

c. Zones (Sections 1, 2, 8, and 9 in Table D8).

[30] P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses*, Interim Report N-10/ADA 031450 (CERL, September 1976).

[31] P. Schomer and B. Homans.

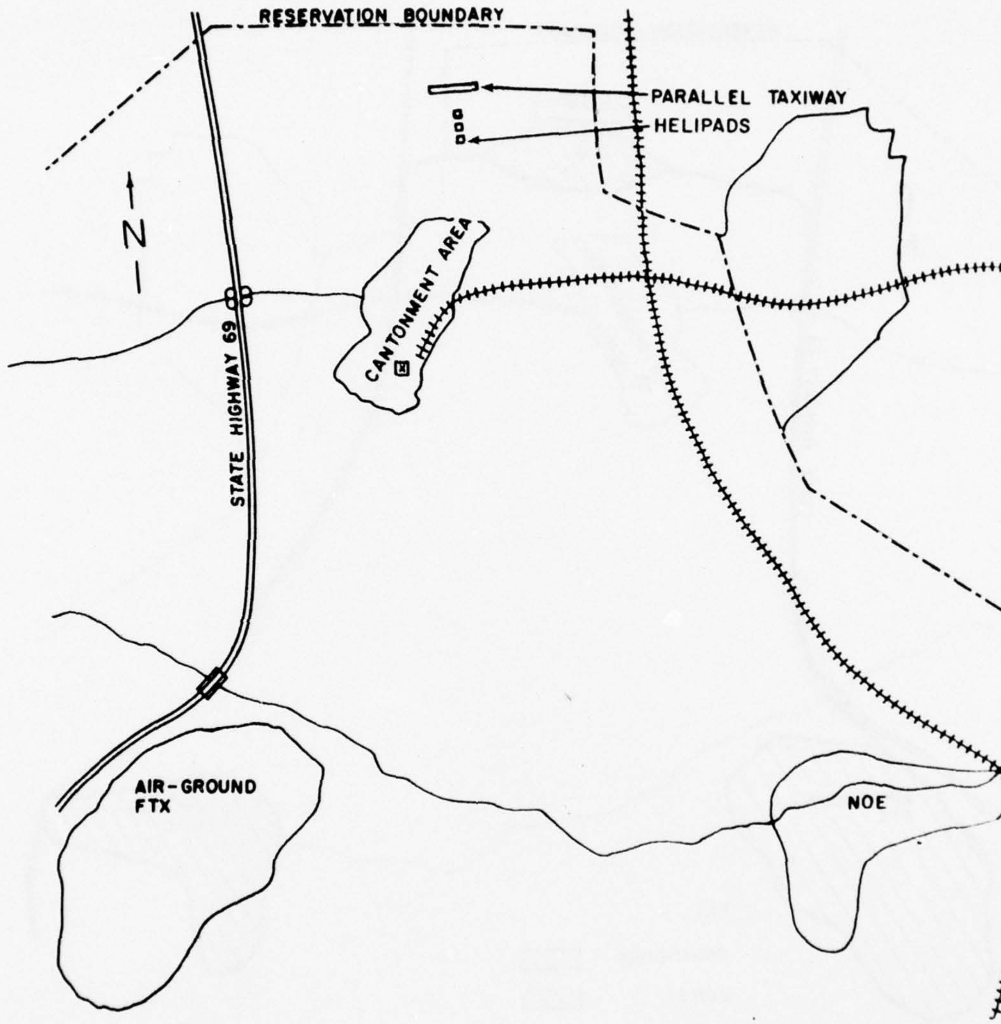


Figure D11. Training areas on Base X. (From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses,* Interim Report N-10/ADA031450 [CERL, September 1976].)

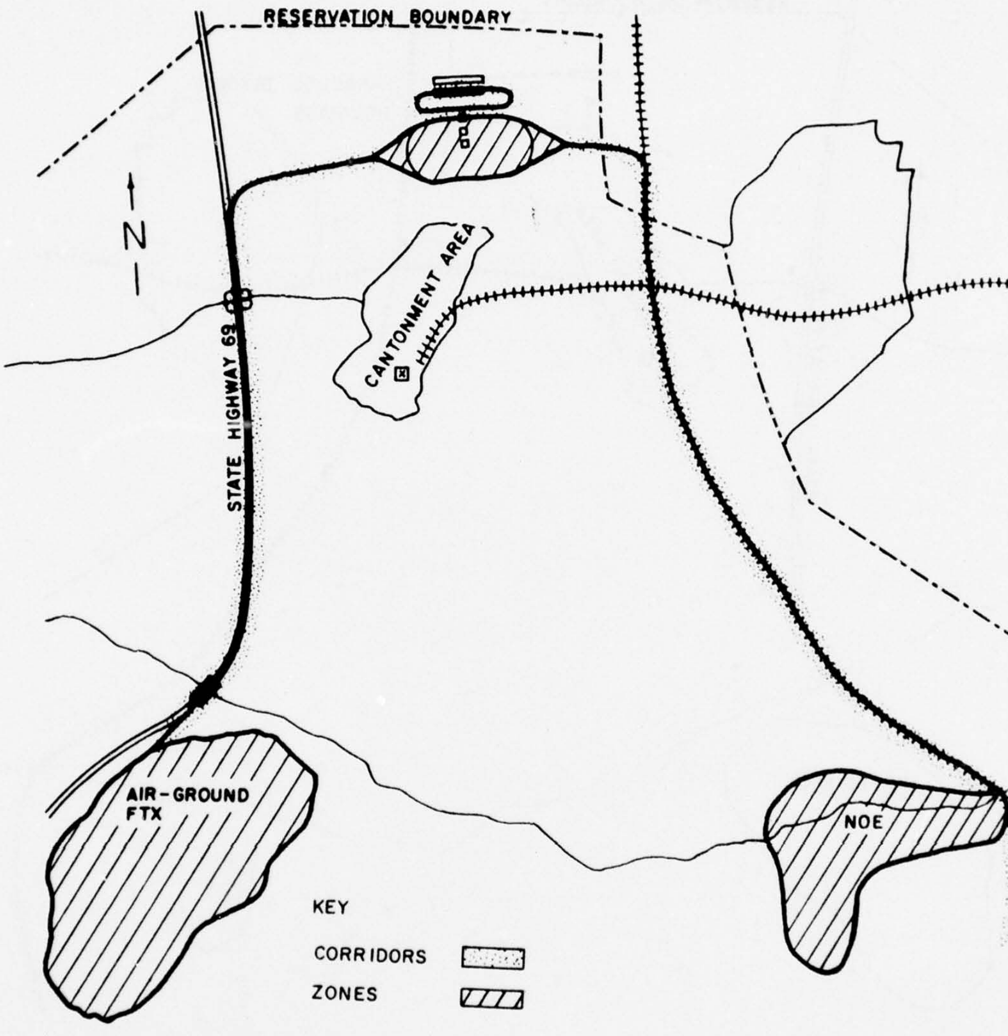


Figure D12. Corridors and zones. (From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses,* Interim Report N-10/ADA031450 [CERL, September 1976].)

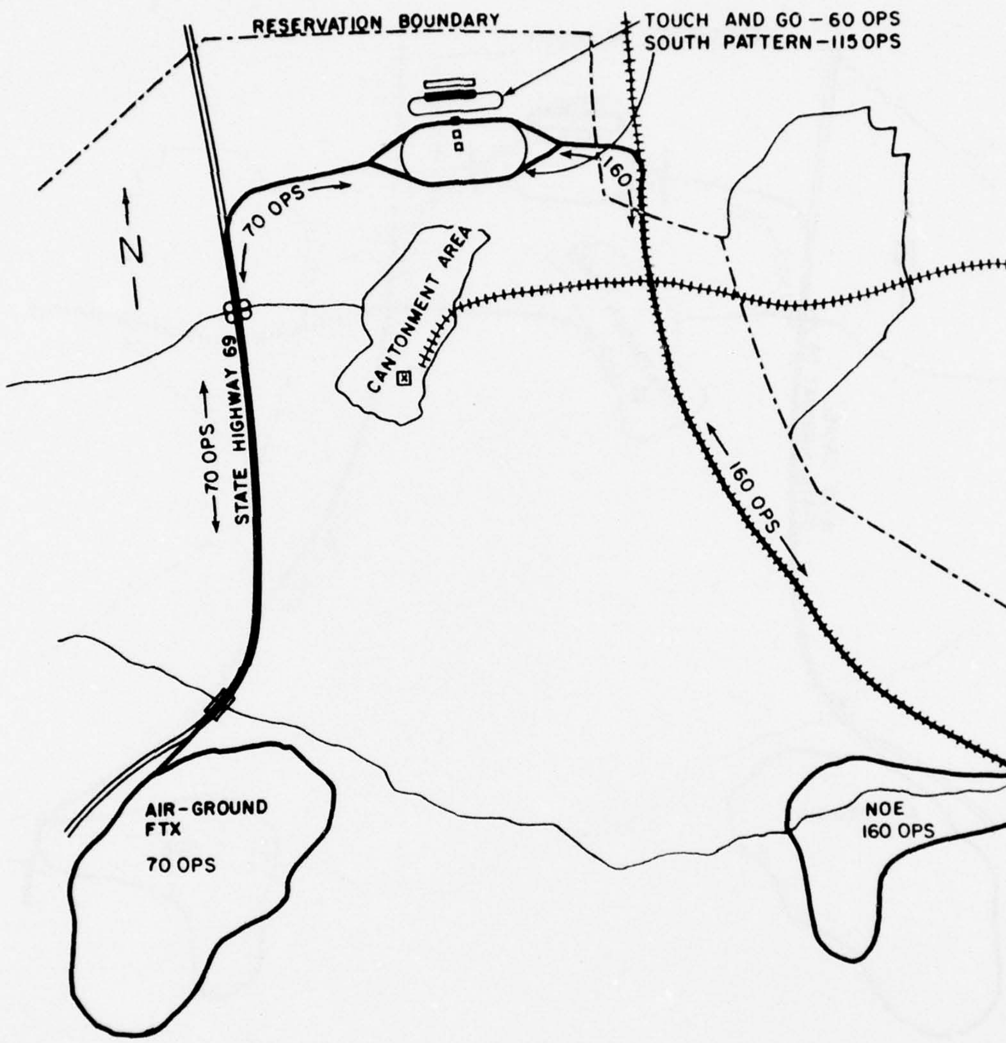


Figure D13. Average daily data.

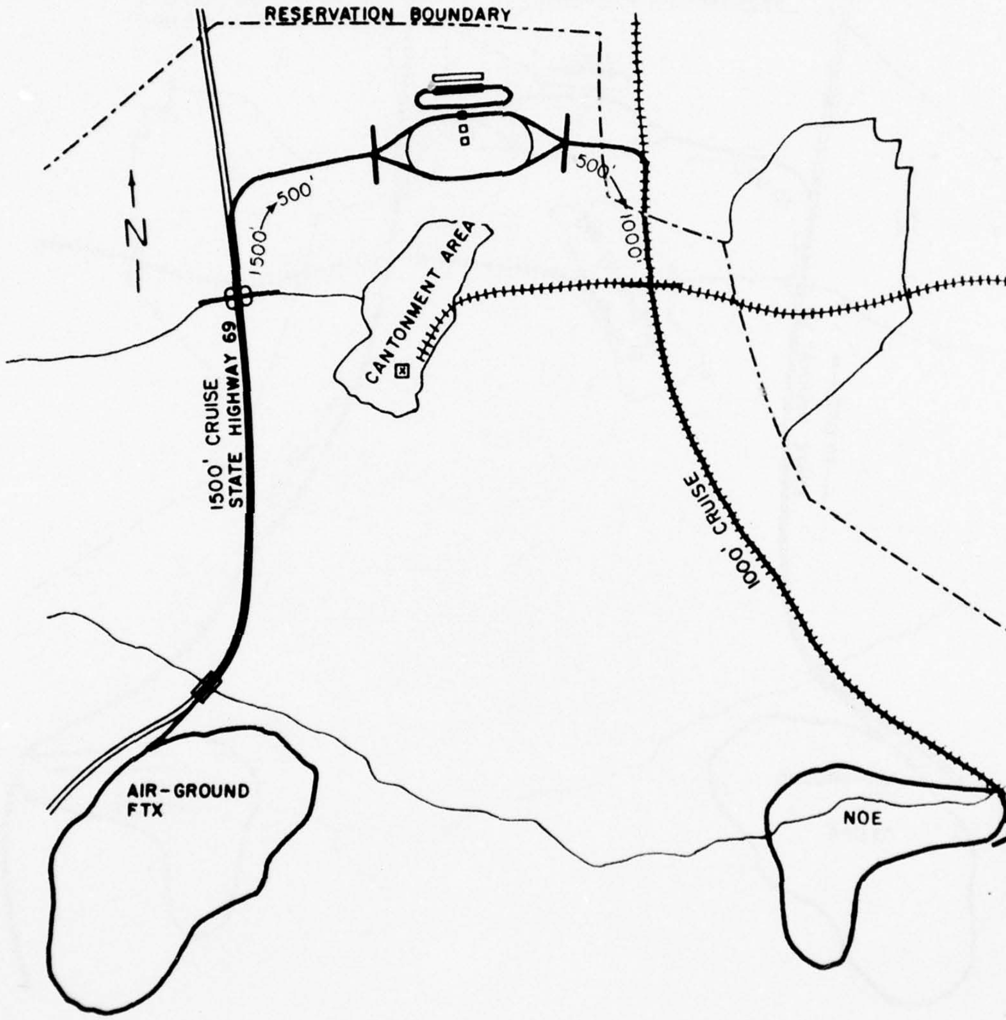


Figure D14. Altitude profiles.

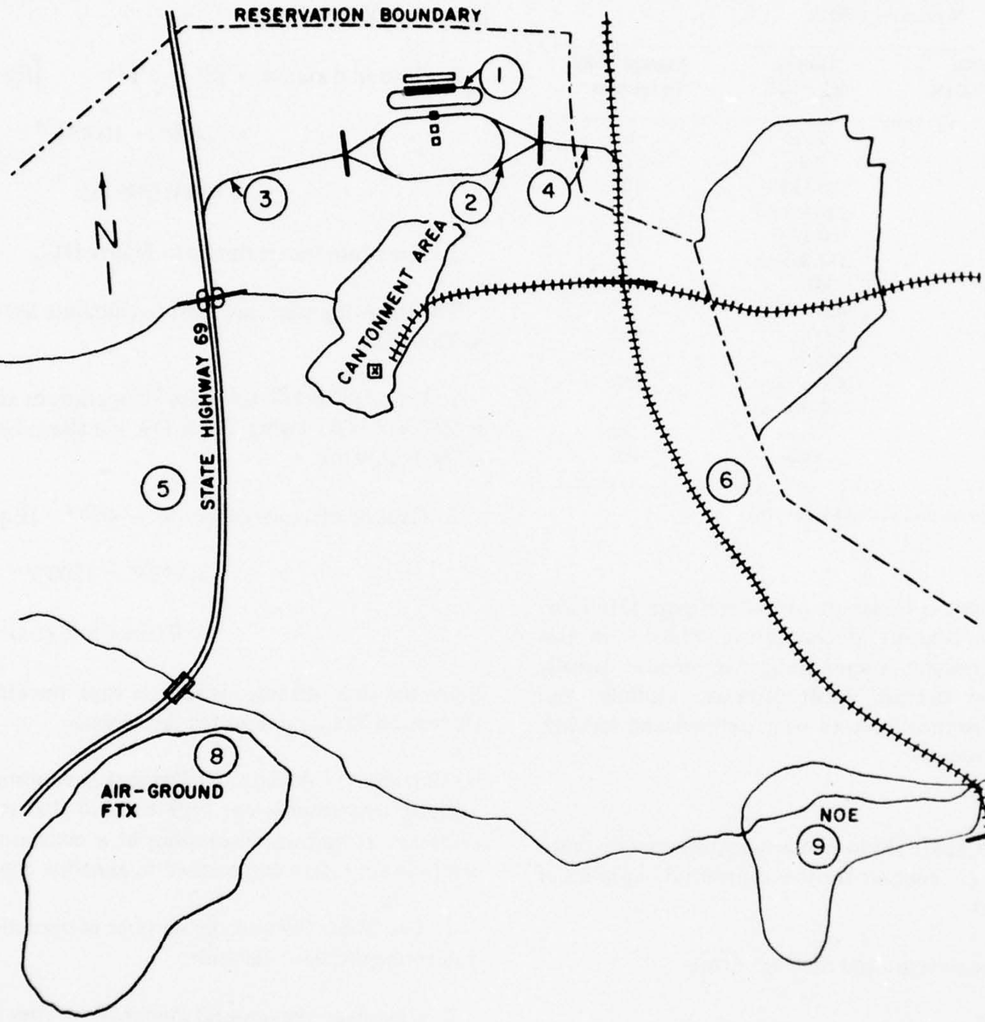


Figure D15. Numbering of zones and corridor sections.

Table D8

Average Daily Operations for Sections

(From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses*, Interim Report N-10/ADA 031450 [CERL, September 1976].)

Section No. (See Figure D15)	Altitude in Ft AGL	Average Daily Operations*
1	Zone	60
2	Zone	115
3	500-1500 (152-457 m)	70
4	500-1000 (152-305 m)	160
5	1500 (457 m)	70
6	1000 (305 m)	160
7	400-1000 (122-305 m)	110
8	Zone	70
*9	Zone	160

*Information taken from Figure D13.

a. Corridors of Constant Altitude. Figure D16 illustrates the concept of contouring. Point 0 in this figure represents a spot along the corridor directly below the aircraft. Slant distance, altitude, and ground distance have all been defined and labeled. To plot contours:

(1) Use Table D9 to find applicable slant distance to the 70 L_{dn} contour for the appropriate number of operations.

(2) Calculate ground distance using

$$\text{Ground distance (X)} = [S^2 - a^2]^{1/2} \text{ for } S \geq a$$

$$= 0 \text{ for } S < a \qquad \text{[Eq D11]}$$

where S = slant distance

a = altitude of aircraft.

(3) Draw contours by measuring this ground distance from the center of the corridor at several locations and drawing a pair of lines paralleling the original corridor.

The following steps are used to calculate Section 6 in Table D8.

1. From Table D8, there are 160 operations at 1000 ft (300 m) AGL. From Table D9 the slant distance is 1400 ft (427 m).

2. $$\text{Ground distance} = [S^2 - a^2]^{1/2} \qquad \text{[Eq D11]}$$

$$= [1400^2 - 1000^2]^{1/2}$$

$$= 980 \text{ ft } (299 \text{ m})$$

3. The contours are drawn in Figure D17.

The following steps are used to calculate Section 5 in Table D8.

1. From Table D8, there are 70 operations at 1500 ft (450 m) AGL. Using Table D9, the slant distance is 750 ft (229 m).

2. $$\text{Ground distance (X)} = [S^2 - a^2]^{1/2} \qquad \text{[Eq D11]}$$

$$= (750^2 - 1500^2)^{1/2}$$

$$= 0 \text{ (since S is } < \text{a)}$$

Since the slant distance is shorter than the altitude, there is no 70 L_{dn} contour for this activity.

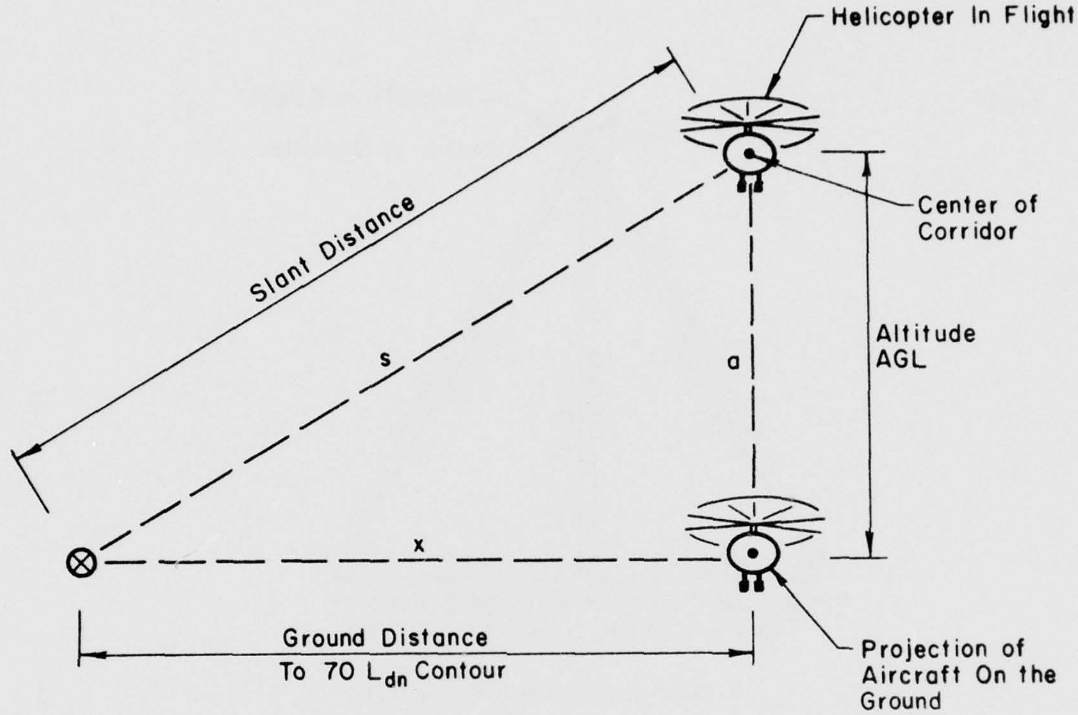
b. Corridors of Ascent and Descent. Assuming that altitude transition is one segment and that the aircraft are ascending/descending at a constant rate, the following steps can be used to generate contours.

1. Use Table D9 and the number of operations to determine the slant distance.

2. Calculate the ground distance for the upper and lower altitudes using Eq D11. Measure these points perpendicular to the center of the corridor where the corresponding altitudes are attained.

3. Connect the measured points on both sides of the corridor to generate contours.

Ascending and descending turns are handled similarly. However, in addition to the starting and ending altitude points, the corridor should be evaluated at two other sections. In Figure D18 an ascending turn starts at altitude W and ends at Z.



AGL	= Above ground distance
Ground Distance	= Distance along ground measured from the projection of the aircraft on the ground to the observer
Slant Distance	= Distance measured from the observer to the center of the corridor

Figure D16. Definition of contouring terms. (From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses,* Interim Report N-10/ADA031450 [CERL, September 1976].)

The corridor has been trisected at X and Y, where X = 1/3 (W + Z) and Y = 2/3 (W + Z). Ground distances are then calculated for each of these *altitudes*. L_{dn} contours are drawn by measuring this ground distance perpendicular to the curve and connecting the measured points. When the turn segment exceeds 90 degrees, the turn should be divided into more than three sections.

The following steps are used to calculate Section 7 in Table D8.

1. There are 110 operations that change altitude from 400 to 1000 ft (122-305 m) AGL. From Table D9, the slant distance is 1100 ft (335 m).

2. Calculate ground distance for upper and lower altitudes.

Ground distance for lower altitude [400 ft (122 m)

AGL] $= [S^2 - a^2]^{1/2} = [1100^2 - 400^2]^{1/2}$

$= 1025$ ft (312 m) AGL [Eq D11]

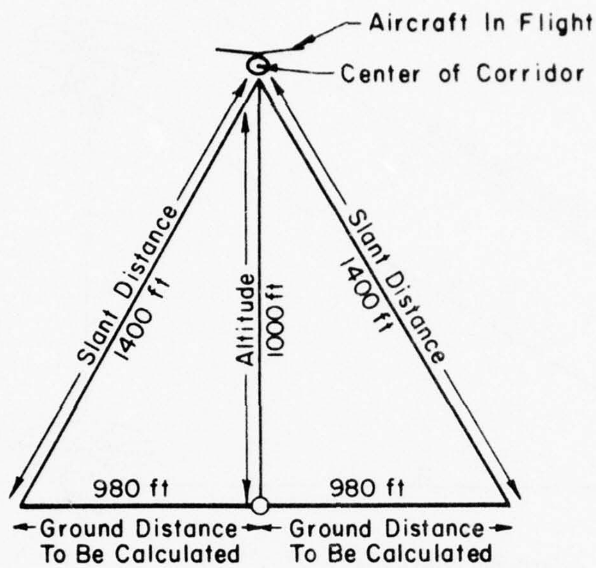
Ground distance for upper altitude [1000 ft

(305 m) AGL] $= [1100^2 - 1000^2]^{1/2}$

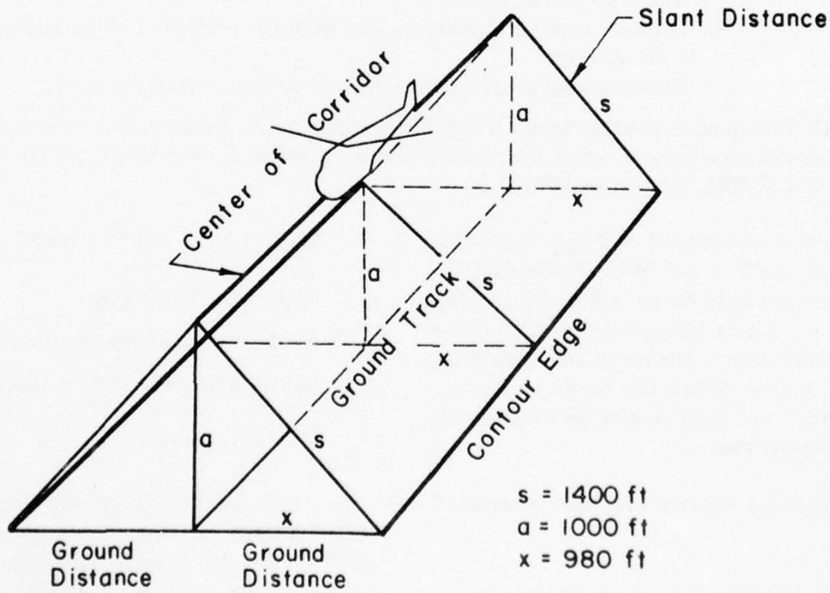
$= 458$ ft (140 m)

3. At the point on the ground where 400 ft (122 m) AGL altitude is attained, the ground distance of 1025 ft (312 m) is measured perpendicular to the center of the corridor. Similarly, 458 ft (140 m) ground distance is measured perpendicular to the center of the corridor where 1000 ft (305 m) AGL altitude is attained.

4. Straight lines are then drawn connecting the measured point on both sides of the corridor to generate two contours (Figure D19).



a. Head-on view of helicopter in flight.



b. Perspective view showing altitude slant distance, center of corridor, and the contour lines paralleling the corridor.

Figure D17. Drawing contours for section 6. (From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses,* Interim Report N-10/ADA031450 [CERL, September 1976].)

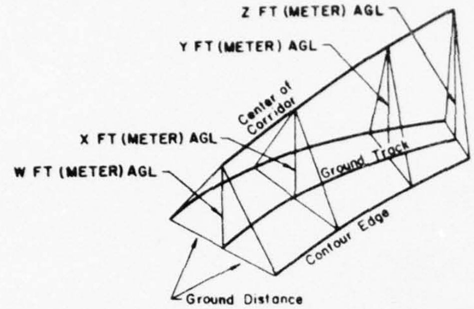


Figure D18. Perspective view of ascending turn. (From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses*, Interim Report N-10/ADA031450 [CERL, September 1976].)

This same procedure is used for Section 4 in Table D8.

The following steps are used to calculate Section 3 in Table D8.

1. There are 90 operations with an altitude change from 500 to 1500 ft (152 to 456 m) AGL. Using Table D9, the slant distance is 750 ft (229 m).

2. Calculate ground distance for upper and lower altitudes.

Ground distance for lower altitude [500 ft (152 m) AGL]

$$X = [S^2 - a^2]^{1/2} \qquad \text{[Eq D11]}$$
$$= [750^2 - 500^2]^{1/2}$$
$$= 559 \text{ ft } (168 \text{ m})$$

Ground distance for upper altitude [1500 ft (456 m) AGL]

$$X = [S^2 - a^2]^{1/2} \qquad \text{[Eq D11]}$$
$$= [750^2 - 1100^2]^{1/2}$$
$$= 0 \text{ (since } S < a\text{)}$$

3. The 70 L_{dn} contour vanishes along the corridor when $[S^2 - a^2]^{1/2} = 0$, or at 750 ft (220 m) AGL. Since the rate of ascent is presumed to be steady, this altitude is attained approximately one-fourth of the way between 500 and 1500 ft (152 and 456 m) AGL. This contour can then be drawn on a map, as in Figure D20, to reflect the change in ground distance as the aircraft makes its ascent to a point where the contour disappears.

Table D9

Calculated L_{dn} Values With Corresponding Slant Distances*

(From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses*, Interim Report N-10/ADA 031450 [CERL, September 1976].)

Average Daily Operations	L_{dn}	Slant Distance**
	75	300 ft (91 m)
10-100	70	750 ft (229 m)
	65	1800 ft (549 m)
	75	400 ft (122 m)
101-150	70	1100 ft (335 m)
	65	2500 ft (762 m)
	75	500 ft (152 m)
151-200	70	1400 ft (427 m)
	65	3000 ft (914 m)
	75	750 ft (213 m)
201-300	70	1800 ft (549 m)
	65	4200 ft (1281 m)

*Table D9 is based on two assumptions:

1. The percentage of nighttime operations is assumed to be 10. Increasing the percentage to 20 or lowering it to 1 would change the noise impact by only two L_{dn} units.

2. A typical fleet mix contains 80 percent UH-1s, 15 percent AH-1Gs, and 5 percent CH-47s. Changes in this mix (e.g., 40 percent UH-1s, 40 percent OH-58s, 15 percent AH-1Gs, and 5 percent CH-47s) would only affect the noise impact slightly. A cruise speed of 80 to 90 knots (148 to 167 km/hour) was used.

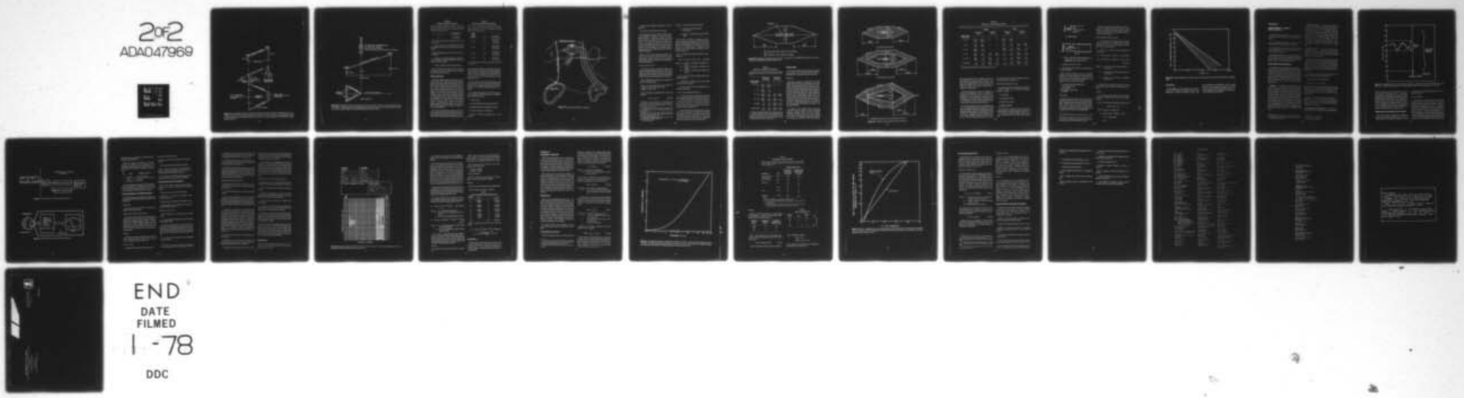
**To draw contours below 65 dB L_{dn}, it can be estimated that the L_{dn} contour will decrease by 4 dB for every doubling of slant distance. To apply this, multiply the slant distance to the L_{dn} 65 contour by 2.3 to get the slant distance to the L_{dn} 60 contour. Then multiply this new distance by 2.3 to obtain the slant distance to the L_{dn} 55 contour, etc.

c. Zones. There are two types of zones—regular and airfield. To draw contours around regular zones, merely plot the appropriate distance in Table D10 from the edge of the zone. This buffer area will provide sufficient protection for moderate future growth. L_{dn} values inside zones are assumed to be above 75 L_{dn}. Activities around airfields are evaluated by the following steps:

1. Determine ground distance using Table D11 and the number of daily operations.

AD-A047 969 CONSTRUCTION ENGINEERING RESEARCH LAB (ARMY) CHAMPAI--ETC F/G 6/6
ENVIRONMENTAL NOISE IMPACT ANALYSIS FOR ARMY MILITARY ACTIVITIE--ETC(U)
NOV 77 R J GOFF, E W NOVAK
UNCLASSIFIED CERL-TR-N-30 NL

2 OF 2
ADA047969



END
DATE
FILMED
1-78
DDC

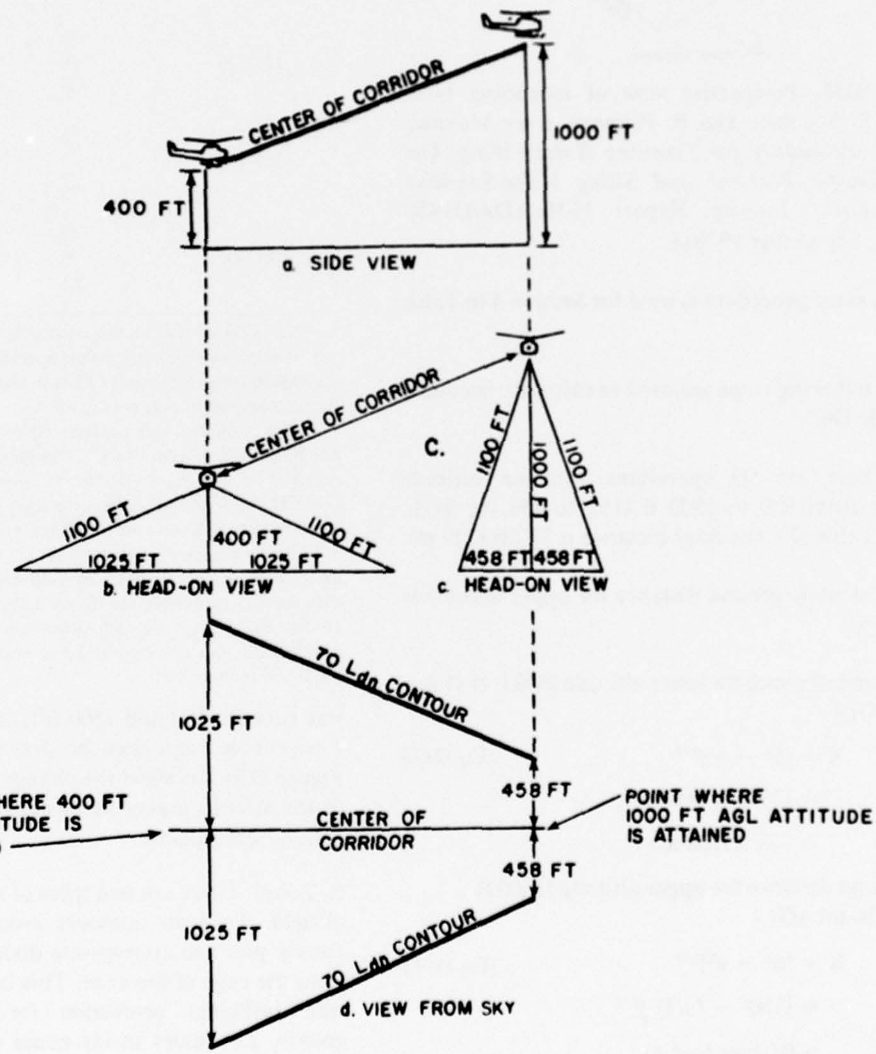


Figure D19. Calculating contours for ascents and descents for Section 7. Metric conversion factor: 1 ft = 0.3048 m. (From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses*, Interim Report N-10/ADA031450 [CERL, September 1976].)

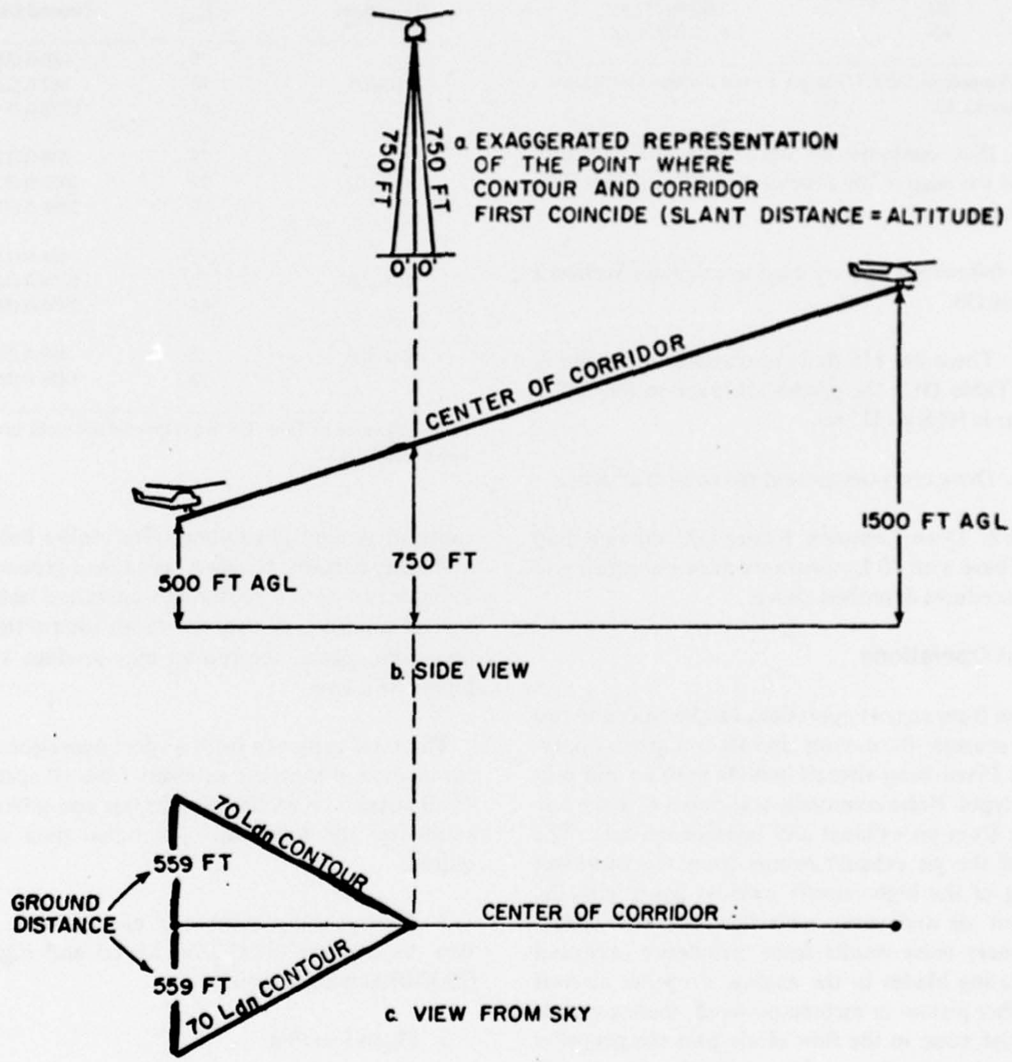


Figure D20. Calculating contours for ascents and descents for Section 3. (From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses,* Interim Report N-10/ADA031450 [CERL, September 1976].)

Table D10

Calculated Ground Distances for Zones

(From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses*, Interim Report N-10/ADA 031450 [CERL, September 1976].)

L_{dn}	Ground Distance*
70	693 ft (211 m)
65	1755 ft (535 m)

*See footnote in Table D9 to get ground distances for contours lower than L_{dn} 65.

2. Plot contours by measuring this distance around the edge of the zone or from the center of the corridor.

The following steps are used to calculate Section 2 in Table D8.

1. There are 115 daily operations in Section 2. From Table D11, the ground distance to the 70 L_{dn} contour is 1058 ft (322 m).

2. Draw contours around the zone of activity.

Step 6. Draw Contours. Figure D21 shows a map of the base with 70 L_{dn} contours drawn according to the procedures described above.

Table D11

Calculated Ground Distances for Airfield Zones

(From P. Schomer and B. Homans, *User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses*, Interim Report N-10/ADA 031450 [CERL, September 1976].)

Average Daily Operations	L_{dn}	Ground Distance
	75	125 ft (38 m)
10-100	70	742 ft (226 m)
	65	1775 ft (541 m)
	75	400 ft (122 m)
101-150	70	1058 ft (322 m)
	65	2381 ft (726 m)
	75	491 ft (150 m)
151-200	70	1316 ft (401 m)
	65	2935 ft (895 m)
201-300	75	687 ft (209 m)
	70	1826 ft (557 m)

*See footnote in Table D9 to get ground distances to contours lower than L_{dn} 65.

Airport Operations

Noise from airport operations can be traced to two major sources: fixed-wing aircraft and ground operations. Fixed-wing aircraft include both jet and propeller types. Noise commonly associated with the former is from jet exhaust and turbo-machinery. The roar of the jet exhaust results from the turbulent mixing of the high-velocity exhaust gases with the ambient air and varies with flow velocity. Turbomachinery noise results from turbulence produced by rotating blades in the engine. Propeller aircraft are either piston- or turbine-powered; these generate the most noise in the flow of air past the propeller blades. A secondary noise source is the aircraft engine, which is dominant at typical take-off power. The small fixed-wing piston aircraft are most common to Army facilities.

The noise of aircraft flyovers differs from that of ground operations. For the same distance, the maximum noise levels produced during a ground operation will be lower than during a flight operation because of ground absorption, intervening buildings, and other barriers. However, because a ground operation or run-up is a continuous operation lasting for several minutes, as opposed to an intermittent flyover noise signal, the run-up may produce a much higher SEL level.

The total exposure from airport operations is the summation of the noise exposure from all operations of all aircraft on all flight paths (air and ground). In summary, the following operational data are required.

1. Average daily number of each aircraft operation, by daytime (0700-2200 hours) and nighttime (2200-0700 hours) periods

2. Flight location

3. Thrust schedule for each aircraft operation

4. Altitude profile for each aircraft operation

5. Noise level data for each operation

6. Runway utilization percentage for each operation

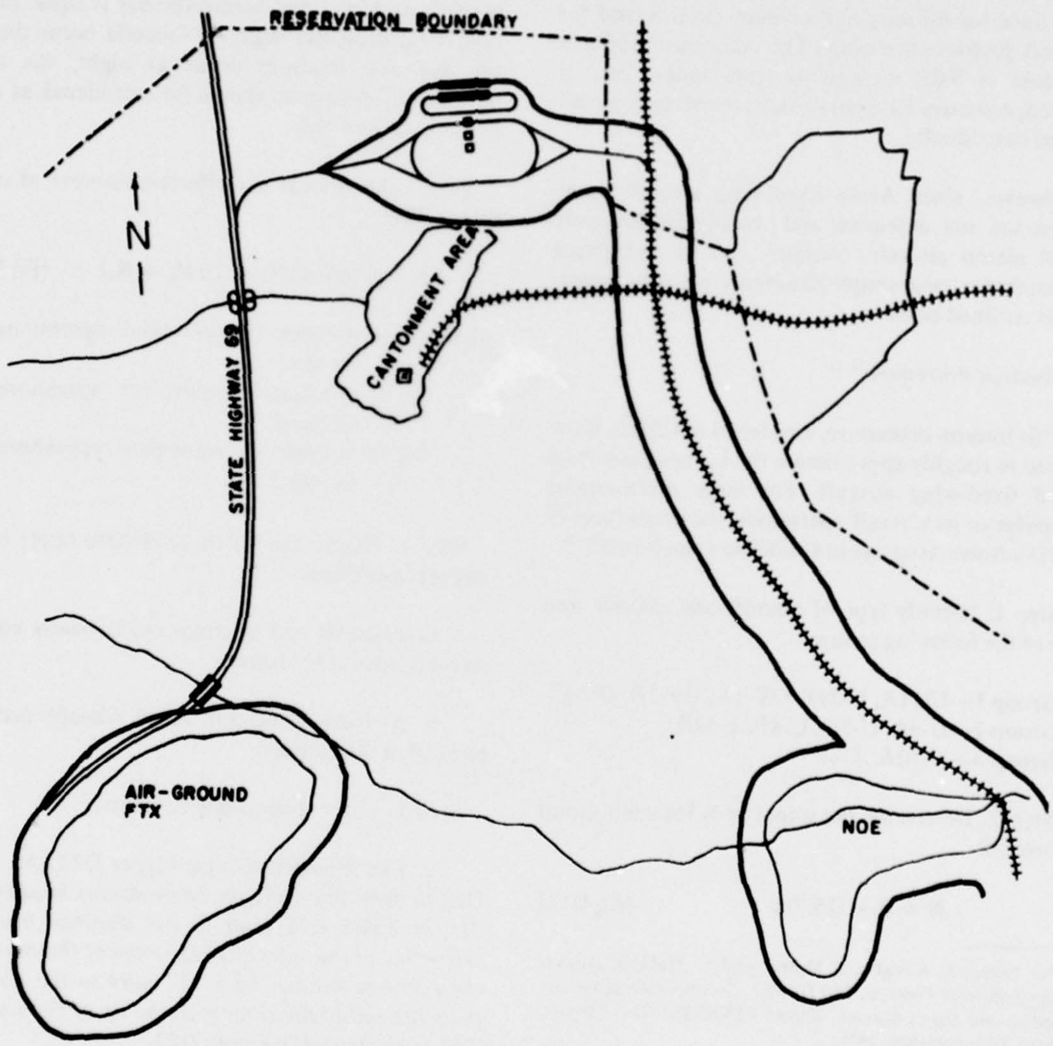


Figure D21. Noise impact map for L_{dn} value of 70.

7. Flight path utilization percentage for each operation

8. Location and orientation of run-up pads.

The complexity of normal airport operations (jet and propeller aircraft activity as well as ground operations) requires a computer program to obtain accurate noise contours within a reasonable time span.[32,33] The files of these programs contain noise level data for military and civilian aircraft and for aircraft performance data. The computer produces contours at 5-dB increments from input data; if desired, contours for a particular aircraft may be obtained individually.

However, since Army fixed-wing aircraft operations are not extensive and usually involve only small piston aircraft, contours can be calculated manually for some simple situations using the procedures outlined below.

Evaluation Procedure[34,35]

This interim procedure, developed at CERL, is designed to roughly approximate the L_{dn} contours from small fixed-wing aircraft. For large multi-engine propeller or jet aircraft operations, the procedures in HUD's Noise Assessment Guidelines can be used.[36]

Step 1. Identify type of aircraft and classify into one of the following groups.

Group 1—U-21A, U-21F, OV-1A, OV-1B, OV-1C
Group 2—U-6A, U-8D, U-8F, T-42B
Group 3—U-10A, T-41

Step 2. Determine the quantity N for each group of aircraft

$$N = d + (16.7)\,n \qquad \text{[Eq D12]}$$

where N = number of equivalent operations

d = number of daytime operations (0700-2200)

n = number of nighttime operations (2200-0700).

Each takeoff or landing is considered an operation. The calculations assume that the number of takeoffs and landings during the day is equal to the number during the night. If takeoffs occur during the day and landings occur at night, the total number of operations should be considered as daytime operations only.

Step 3. Determine the effective number of operations, EN:

$$EN = 1/40\,(40\,N_1 + 10\,N_2 + N_3) \qquad \text{[Eq D13]}$$

where N_1 = number of equivalent operations for Group 1
N_2 = number of equivalent operations for Group 2
N_3 = number of equivalent operations for Group 3

Step 4. Determine which conditions apply to the airport operations.

a. Takeoffs and landings occur nearly equally on both sides of the runway.

b. At least 80 percent of all takeoffs occur at one end of the runway.

Step 5. Draw appropriate contours.

a. For situation 4a, use Figure D22 and Table D12 to draw the contours; *the columns headed by a "1" in Table D12 refer to the distance from the centerline of the runway to the edge of the contours; the columns headed by a "2" refer to the distance from the end of the runway to the tip of the contour. This is illustrated in Figure D22.*

b. For situation 4b, use Figure D22 and Table D13 to draw the contours. The distances in the landing column are used for the runway end over which the landings occur; the distances in the takeoff column are used for the runway end over which takeoffs occur. Examples are shown in Figure D23.

---

[32] C. Bartel, C. Couglin, J. Moran, and L. Watkins, *Airport Noise Reduction Forecast, Vol II, NEF Computer Program Description and User's Manual,* Report # DOT-TST-75-4 (Department of Transportation, 1975).

[33] *Community Noise Exposure Resulting From Aircraft Operations,* AMRL-TR-73-10 C Series (Aerospace Medical Research Laboratory, 1971).

[34] *Predicting the Noise Impact From Small Propeller-Driven Fixed-Wing Aircraft Operations,* Draft Technical Letter (Office of the Chief of Engineers [OCE], 1974).

[35] T. Schultz and N. McMahon, *HUD Noise Assessment Guidelines,* BBN Report 2176 (BBN, August 1971).

[36] Schultz and McMahon.

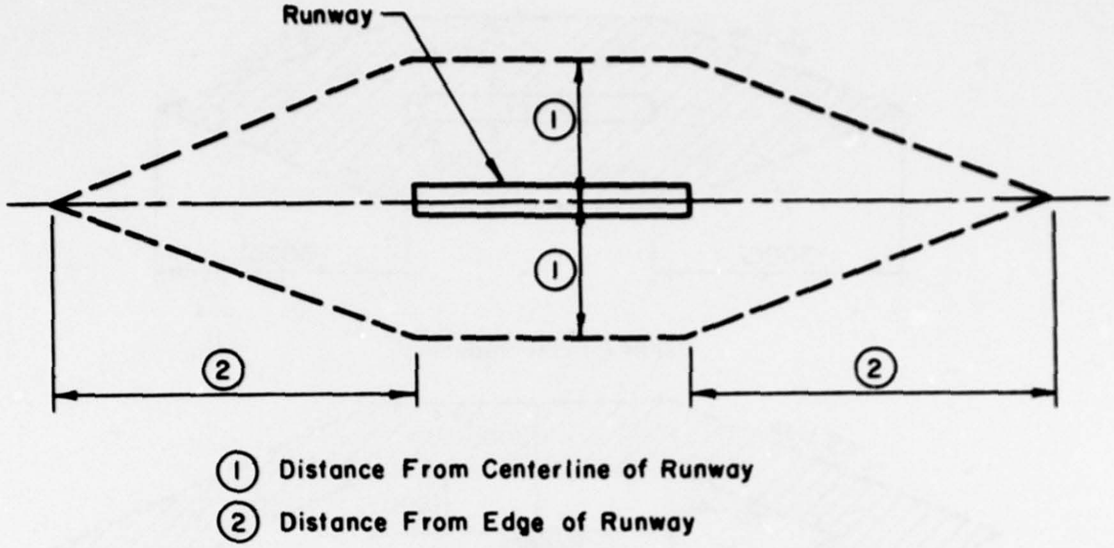


Figure D22. Construction of zone contours. (From T. Schultz and N. McMahon, *HUD Noise Assessment Guidelines*, BBN Report 2176 [BBN, August 1971].)

Table D12

Distances to L_{dn} Contours for Airport Operations

(From *Predicting the Noise Impact From Small Propeller-Driven Fixed-Wing Aircraft Operations*, Draft Technical Letter [OCE, 1974].)

Effective Number of Operations	Distance to* L_{dn} 65 Contour 1	Distance to* L_{dn} 65 Contour 2	Distance to* L_{dn} 70 Contour 1	Distance to* L_{dn} 70 Contour 2
0 - 50	500 ft 152 m	3000 ft 914 m	0	0
51 - 100	1000 ft 305 m	1 m 1.6 km	0	0
101 - 200	1500 ft 456 m	1½ mi 2.4 km	500 ft 125 m	3000 ft 914 m
201 - 400	2000 ft 609 m	2 mi 3.2 km	1000 ft 305 m	1 mi 1.6 km
401 -1000	1 mi 1.6 km	2 mi 3.2 km	2000 ft 609 m	1½ mi 2.4 km
more than 1000	1 mi 1.6 km	2½ mi 4 km	3000 ft 914 m	1½ mi 2.4 km

*To draw contours below 65 dB L_{dn}, it can be estimated that the L_{dn} contour will decrease by 4 dB for every doubling of distance. To apply this, multiply the L_{dn} 65 contour distance by 2.5 to get the distance to the L_{dn} 60 contour. Then multiply the new distance by 2.3 to get the distance to the L_{dn} 55 contour, etc.

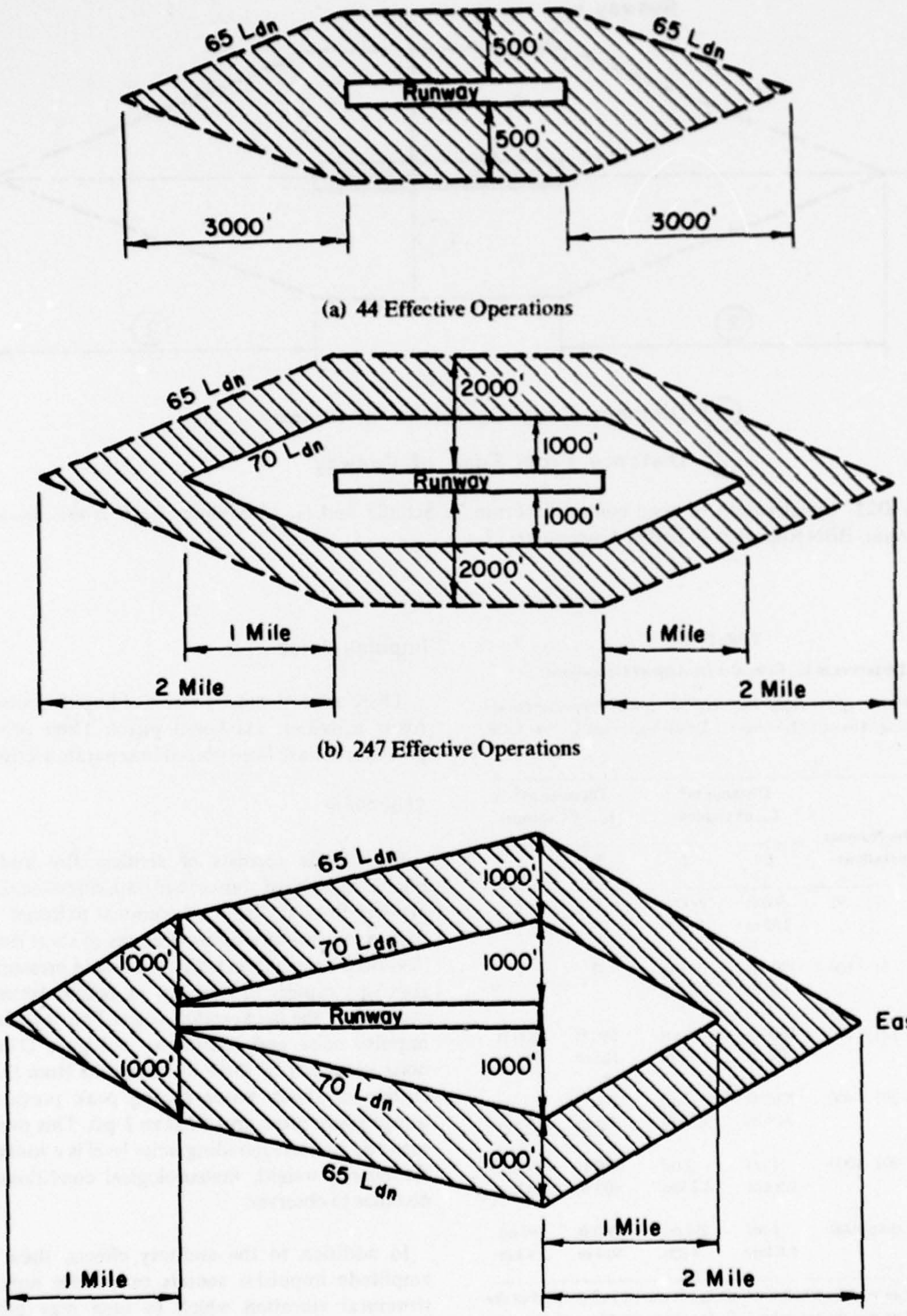
Impulse Noise

There are two major sources of impulse noise from Army activities: blast and pistol. Their predictive procedures have been placed in separate sections.

Blast Noise

Blast noise consists of artillery fire and shell bursts. Most blast sources are omnidirectional, while artillery fire has distinct directional patterns. Nonetheless, all produce discrete noises of short duration (less than 1 second) in which the sound pressure level rises very rapidly to a high peak before decaying to the level of the background noise. This is defined as impulse noise and illustrated in Figure D24. The noise produced by these blasts results from the generation of shock waves having peak pressures or overpressure often greater than 1 psi. This overpressure and its corresponding noise level is a function of the charge weight, meteorological conditions, and distance to observer.

In addition to the auditory effects, these large amplitude impulsive sounds can excite noticeable structural vibration which in turn may generate additional annoyance because of "house rattling" and "startle." To account for these, the C-weighted sound exposure level (CSEL) is used for assessing the



(c) 162 Effective Operations; 85% of takeoffs are to the east

Figure D23. *Zones for various effective number of operations.*

Table D13

Distance to L_{dn} Contours (Landing and Takeoff)

(From *Predicting the Noise Impact From Small Propeller-Driven Fixed-Wing Aircraft Operations*, Draft Technical Letter [OCE, 1974].)

Effective Number of Operations	Landings				Takeoffs			
	*Distance to L_{dn} 65		*Distance to L_{dn} 70		*Distance to L_{dn} 65		*Distance to L_{dn} 70	
	1	2	1	2	1	2	1	2
0 - 50	500 ft 152 m	3000 ft 914 m	0	0	1000 ft 305 m	3000 ft 914 m		
51 - 100	500 ft 152 m	3000 ft 914 m	0	0	1500 ft 456 m	1 mi 1.6 km	500 ft 152 m	3000 ft 914 m
101 - 200	1000 ft 305 m	1 mi 1.6 km	0	0	2000 ft 609 m	1½ mi 2.4 km	1000 ft 305 m	1 mi 1.6 km
201 - 400	1500 ft 456 m	1½ mi 2.4 km	500 ft 152 m	3000 ft 914 m	1 mi 1.6 km	2 mi 3.2 km	2000 ft 609 m	1½ mi 2.4 km
401 - 1000	2000 ft 609 m	2 mi 3.2 km	1000 ft 305 m	1 mi 1.6 km	1 mi 1.6 km	2 mi 3.2 km	3000 ft 914 m	1½ m 2.4 km
more than 1000	1 mi 1.6 km	2 mi 3.2 km	2000 ft 609 m	1½ mi 2.4 km	1 mi 1.6 km	2½ mi 4.0 km	3000 ft 914 m	1½ mi 2.4 km

*To draw contours below 65 dB L_{dn}, refer to the footnote in Table D11.

high energy impulse noise. C-weighted sound levels are obtained by using an electric network in the noise instrumentation similar to the A-network. The methods to obtain CSEL are otherwise identical to ASEL. The CSEL is then used to compute the C-weighted L_{dn} using Eq D2.

Using the present state of the art, C-weighted L_{dn} levels can be interpreted in terms of annoyance in residential areas with the same noise level scale applicable for the A-weighted L_{dn}. In addition, these C-weighted L_{dn} levels are added logarithmically to the A-weighted L_{dn} levels of other sources to obtain composite noise exposure for an environment.

As with other major sources, the two major factors used to determine blast noise exposure are noise level and number of operations during daytime and nighttime periods. However, determination of blast noise level is complicated by many operational factors, the most significant being meteorological conditions. Wind and temperature gradients can create focusing conditions which have significant effects on the sound levels up to 10 miles.[37,38]

Blast Noise Evaluation Procedure

To determine the SEL of a single blast, shell burst, or artillery firing event, the following parameters must be considered:

1. Size of charge
2. Time history of event
3. Distance from source
4. Directivity pattern

---

[37] P. D. Schomer, R. J. Goff, and L. Little, *The Statistics of Amplitude and Spectrum of Blast Propagated in the Atmosphere*, Technical Report N-13/ADA033475 (CERL, November 1976).

[38] P. D. Schomer, *Predicting Community Response to Blast Noise*, Technical Report E-17/AD# 773690 (CERL, December 1973).

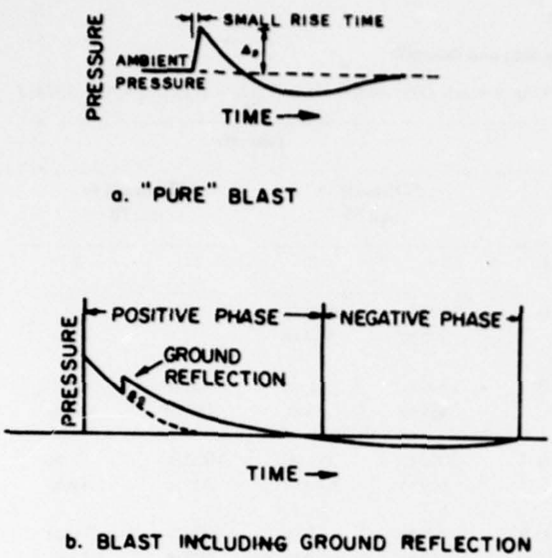


Figure D24. Typical blast impulse.

5. Frequency spectrum of event

6. Wind speed, wind direction, and temperature at various altitudes.

Since the time involved to do even a simple manual calculation is almost prohibitive, CERL has developed a computer program to generate blast noise contours.[39,40] Complete information on this program can be obtained by contacting:

U.S. Army Construction Engineering
Research Laboratory
P.O. Box 4005
Champaign, Illinois 61820
Attn: ENA

Pistol Range

Although noise from small arms such as pistols and rifles is impulsive in nature, it has a significantly higher frequency and lower energy than blast noise. Thus, since the event will not have the same effects as blast noise (induced vibrations and startle), the A-weighted noise pressure is a more appropriate descriptor of the event than the C-weighted SEL.

Figure D25 presents ASEL values at various distances for a single pistol round. Similar to other sources, the number and time of events must also be considered to determine the total exposure. The procedure is outlined below.

Pistol Range Evaluation Procedure

1. Use Figure D25 to determine ASEL for a single round of ammunition at a desired distance. The line bordering the top of the fan should be used since it predicts worst case situations.

2. Determine L_{dn} and L_{eq} for the total number of rounds from:

$$L_{eq} = \text{ASEL/round} + 10 \log_{10} n - 35.6 \quad \text{[Eq D14]}$$

$$L_{dn} = \text{ASEL/round} + 10 \log_{10} [n_d + 10n_n] - 49.4 \quad \text{[Eq D15]}$$

where n = total number of rounds fired within a 1-hour period

n_d = number of rounds fired in the daytime [0700-2200]

n_n = number of rounds fired at nighttime [2200-0700]

3. Adjust for other distances of interest by using Figure D25 for these distances and repeating steps 1 and 2.

Example

At a pistol range, 400 rounds are fired each hour at each of 25 positions. What is the L_{eq} at 1000 ft (300 m)?

Step 1. From Figure D25 determine ASEL/round

$$\text{ASEL/round} = 70$$

Step 2. Compute L_{eq} from Eq D14

$$L_{eq} = \text{ASEL/round} + 10 \log_{10} n - 35.6$$

$$= 70 + 10 \log_{10} 10000$$

$$= 74.4$$

---

[39] P. D. Schomer, *Predicting Community Response to Blast Noise.*

[40] B. Homans, J. McBryan, and P. Schomer, *User Manual for the Acquisition and Evaluation of Operational Blast Noise Data*, Technical Report E-42/AD# 782911 (CERL, July 1974).

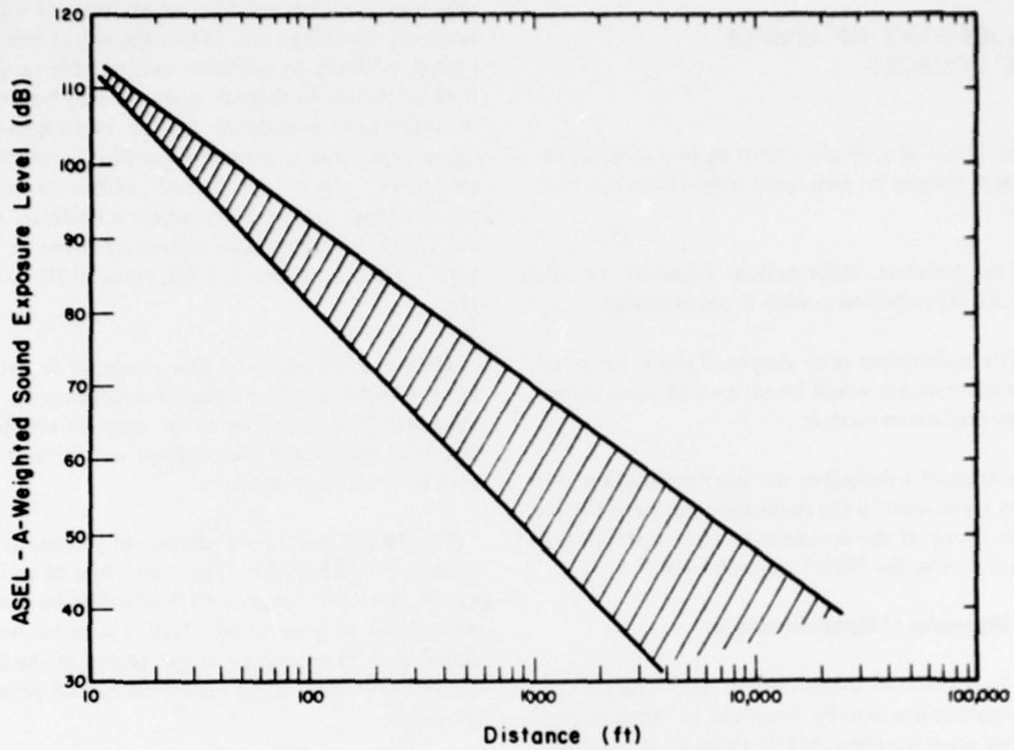


Figure D25. ASEL predictions for a single round of ammunition. (From field data obtained by J. McBryan, CERL.)

Conclusions

The procedures in this appendix can be used to generate noise contours resulting from most Army operations. It should be cautioned, however, that these procedures are applicable only for simple situations. As the complexity increases, the use of an outside consultant will become necessary. These contours, nonetheless, are an integral part of the assessment procedures in the main text.

APPENDIX E:

MEASUREMENT OF SIMPLE NOISE SOURCES

Noise levels of a single source or of a general environment should be measured only under two conditions:

1. The baseline information required in the Appendix D prediction models is not available.

2. The assessment is so simple (Type I, see p 34) that measurements would be easier and more accurate than prediction models.

This appendix describes the instrumentation and outlines steps used in the measurement and analysis process. Many of the concepts herein are developed from a report by the Wyle Research Labs.[41]

Basic Equipment Specifications

The functions of measurement and analysis instrumentation are usually described in terms of performance specifications. While there is an extensive vocabulary for defining these specifications, many are in a mathematical or detailed technical format. Since a basic understanding of equipment is vital for determining data reliability, the following terms have been simplified to define these performance specifications.

Accuracy[42] — The precision with which the output of a device actually represents the theoretical value it is supposed to represent. The degree of precision results from a practical compromise based on the measurement state of the art and the cost of producing the device. Accuracy is commonly expressed in terms of the range within which the actual measured output falls as an approximation of the true environment. Ideally, this accuracy is also specified by its confidence limits. For example, the accuracy of a complete high quality noise monitoring system might be specified by a 95 percent confidence that the measured value is within ± 1 dB of the true value.

Frequency Response[43] — The range of frequencies which may be processed by the instrument within its accuracy specifications. When the signal being processed contains frequencies outside this range, the data contained in these frequencies may be distorted or otherwise invalidated by the instrument. Frequency response is normally specified in terms of the frequency range (in Hertz) within which the input/output amplitude response is uniform. A typical range for acoustical instrumentation is a uniform response, within ± 2 dB, from 50 Hz to 15,000 Hz.

Dynamic Range[44] — The range of input noise levels which may be measured accurately by an instrument. The dynamic range may be set forth in terms of the lowest and highest noise levels which may be accurately measured.

The "high" end of an instrument's dynamic range is limited by distortion. The "low" end of an instrument's dynamic range is established by its electrical noise level or noise floor. This is a noise (voltage) which may be measured at the output of the instrument when there is no acoustical signal present at the input.

For example, a standard sound level meter may be provided with the following specifications:

Dynamic Range: 30 dB to 120 dB

Meter Range: −10 to 10 dB

This means that the sound level meter will accommodate a range of noise levels from 30 dB to 120 dB in 20-dB increments. Attenuator switching is required for the indicating meter to measure this range of noise levels.

Figure E1 illustrates the concept as applied to a sound level meter. The dynamic range of the instrument is indicated on the right side of the figure and the range of meter levels which may be read is illustrated on the other side.

Environmental Characteristics[45] — The extent to which an instrument will meet its measurement per-

[41] *Community Noise Monitoring—A Manual for Implementation*, Technical Report WR 76-8 (Wyle Laboratories, July 1976).
[42] *Community Noise Monitoring*.
[43] *Community Noise Monitoring*.
[44] *Community Noise Monitoring*.
[45] *Community Noise Monitoring*.

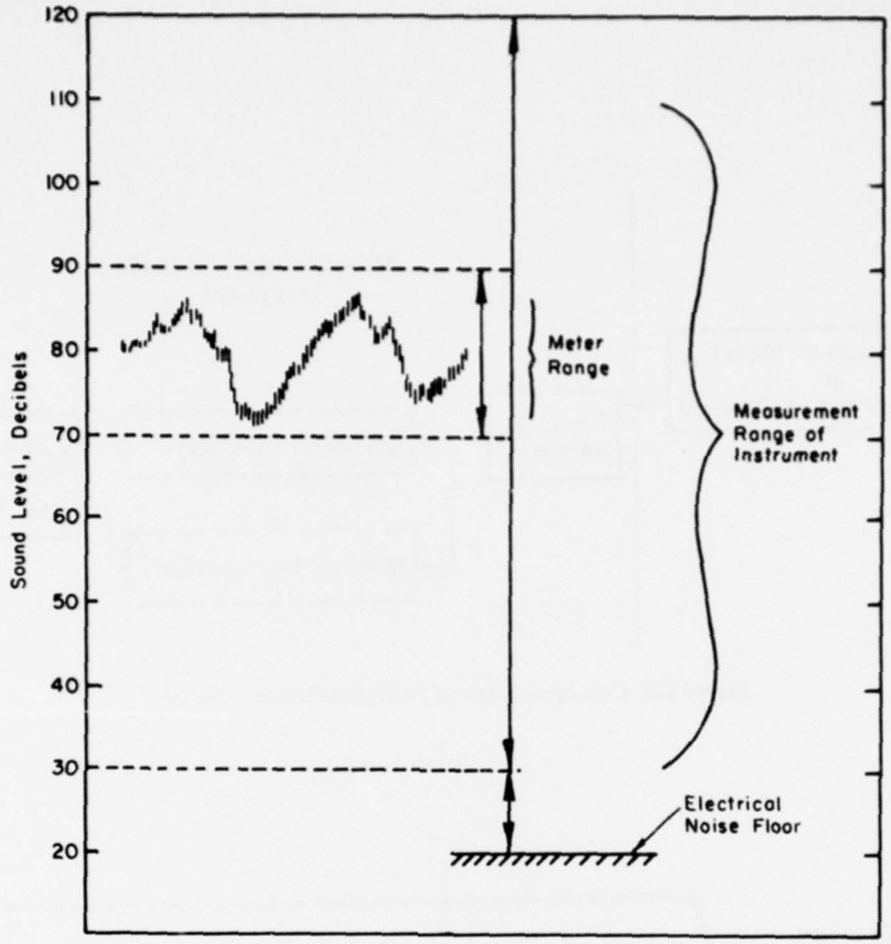


Figure E1. Simplified illustration of the dynamic range of a sound level meter. (From *Community Noise Monitoring—A Manual for Implementation,* Technical Report WR 76-8 [Wyle Laboratories, July 1976].)

formance specifications while operating in an adverse physical environment. This is a significant specification for equipment which must be operated outdoors and left unattended for prolonged periods. Specifications are set forth in terms of resistance to moisture, wind, rain, salt spray, and temperature extremes. Equipment is designed either for outdoor use or for laboratory operation, since application to outdoor unmanned sites can impose costly requirements not needed for laboratory instruments.

Measurement and Analysis Instrumentation

Since a broad range of equipment is available to measure and analyze community noise, "instrumentation systems" are frequently assembled to record and analyze data. Figure E2 illustrates the basic concept of the system.

Sound Level Meter

The sound level meter (Figure E3) is a portable instrument used to measure noise levels. It may be broken down into the following major elements: a transducer (microphone) to convert a pressure fluctuation into an electrical voltage; an amplifier to raise the electrical signal to a usable level; a calibrated attenuator to adjust the amplification to a value appropriate to the sound level being measured; a meter to display the measured level; weighting networks to modify the frequency characteristics of the response; an output amplifier and calibrated output

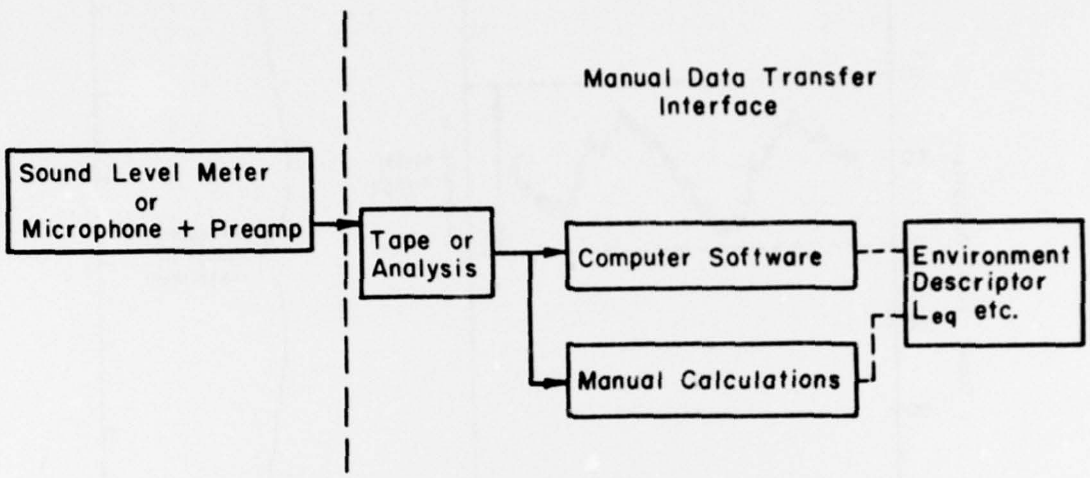


Figure E2. Concep[illegible]ual view of basic measurement system.

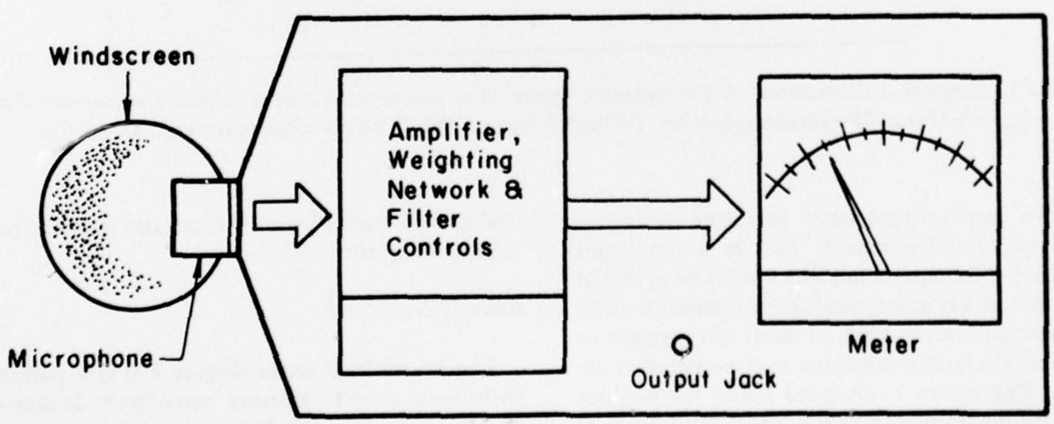


Figure E3. Illustration of typical sound level meter elements.

attenuator; and an output jack to carry the signal to additional instrumentation.

Sound level meters are classified for accuracy according to standard criteria developed by the American National Standards Institute (ANSI). As shown below, four types of instruments are identified.

Type	Name	Suitability for Army Use
1	Precision	Long-Term Monitoring
2	General Purpose	General Environmental Assessment
3	Survey	Not Suitable
S	Special Purpose	Not Suitable

Type 2 instrumentation is generally acceptable for assessment purposes. An impulse sound level meter is also available with substantially more accuracy for measuring highly variable and impulsive sounds.

General Guidelines for Field Measurement

The following general guidelines are helpful for obtaining simple field measurements with the sound level meter.

Identification

Record the time, date, operator, and site location number on the site data sheet.

Measurement Location and Site Layout

Sketch the site layout and note its proximity to any major nearby noise sources. Note all significant dimensions, topographic details, heights of source, or presence of nearby reflecting surfaces. Also note ground cover in the immediate proximity of the measurement and the position of walls or fences between any major nearby source and the measurement location.

Weather

Record the wind speed and direction, and, if possible, temperature and humidity. Note any rain, snow, wet pavement, sleet, or heavy fog.

Source Activity

Note general activity of major nearby sources.

Measurement Instrumentation

Calibrate the instruments before and after measurement.

Check batteries before and after measurement.

Use a windscreen for outdoor measurements. If possible, curtail measurement when wind velocity exceeds approximately 10 mph (16 km/hr).

Set instrument so that during measurements, the readings are made as near mid-scale as possible.

Specific Measurement Procedures[46]

This section provides sound level meter procedures used to measure and analyze the following sources:

Single-event noise sources (vehicle passbys)

Multi-event noise sources (construction sites, industrial sources, etc.)

General acoustic environment (no specific source).

These procedures are *not* applicable for the measurement of impulsive noise.

Single Event Noise Source

These procedures are used mainly for vehicle passbys.

1. Fill in all applicable parts of the noise survey data log (Figure E4).

2. Locate the microphone 1.2 m (4.0 ft) above ground level, preferably on a tripod and at least 6 m (20 ft) from any large reflecting surfaces. The source and microphone should be close enough so that the source is clearly audible, but no closer than 50 ft (15 m).

3. Set the sound level meter to the A-weighting and fast response.

---

[46] *Community Noise Monitoring—A Manual for Implementation*, Technical Report WR 76-8 (Wyle Laboratories, July 1976).

4. Observe the sound level meter during each event and mark the maximum level in the appropriate 2-dB-wide noise level band on the data log.

5. Measurements should not be made when noises from extraneous sources are not at least 6 dB below the levels of the source of interest.

6. After all events have been measured, count the number for occurrences within each 2-dB noise band and write the number in the "Total" column on the right side of Figure E4. The data can then be analyzed according to procedures in the *Data Analysis* section at the bottom of this page.

Multiple Event Single Noise Source

This procedure is used for such sources as construction sites, combat vehicle maneuvers, industrial operations, etc.

1. Fill in all applicable parts of the data log (Figure E4).

2. Locate the microphone 1.2 m (4 ft) above ground level, preferably on a tripod and at least 6 m (20 ft) from any large reflecting surfaces. The source and the microphone should be close enough that the source is clearly audible but no closer than 50 ft (15 m).

3. Determine directionality by walking around the source at a fixed distance and listening for any variations in the sound level. A noise source is said to be directional if it radiates considerably more sound energy in one direction than another. Conversely, a uniformly radiating source would have a sound field surrounding it that does not depend on angle. For uniformly radiating sources, only a few measurements (theoretically only one) at a specified distance should then be required to adequately describe the source. For a directional source, measurements should be taken in the loudest location and used as a worst case.

4. Set the sound level meter to A-weighting and fast response.

5. Record the exact time that the sample will start, and plan for a time when it should end. (The measurement should be at least 10 minutes.)

6. During the sample period, record the instantaneous meter reading every 15 seconds in the appropriate 2-dB-wide noise band shown in Figure E4. For more accuracy, meter readings may be recorded at intervals less than 15 seconds.

7. At the end of each sampling period, count the number of occurrences within each 2-dB noise band and write the number in the "Total" column on the right side of Figure E4. Record the concluding time of the sample in the upper lefthand corner box. The data can then be analyzed according to procedures in the *Data Analysis* section at the bottom of this page.

The General Outdoor Acoustic Environment

This procedure is used to determine data for use in the Type I NED analysis in Chapter 3 (Table 13).

1. Fill in all applicable parts of the data log (Figure E4).

2. Locate the microphone 1.2 m (4 ft) above ground level, preferably on a tripod and at least 6 m (20 ft) from any large reflecting surfaces.

3. Set the sound level meter to A-weighting and slow response.

4. Record the exact time that the sample will start, and plan for a time when it should end. The measurement should be at least 20 minutes.

5. During the sample period, record the instantaneous meter reading every 15 seconds in the appropriate noise band shown in Figure E4. For more accuracy, meter readings may be recorded at intervals less than 15 seconds.

6. At the end of each sampling period, count the number of occurrences within each 2-dB noise band, and write the number in the "Total" column on the right side of Figure E4. Record the concluding time of the sample in the upper left-hand corner box. The data can then be analyzed according to procedures discussed in the Data Analysis Section.

Data Analysis

Raw data from field measurements can be analyzed by either statistical levels (L_{10}, L_{50}, L_{90}) or energy levels (L_{eq} and L_{dn}).

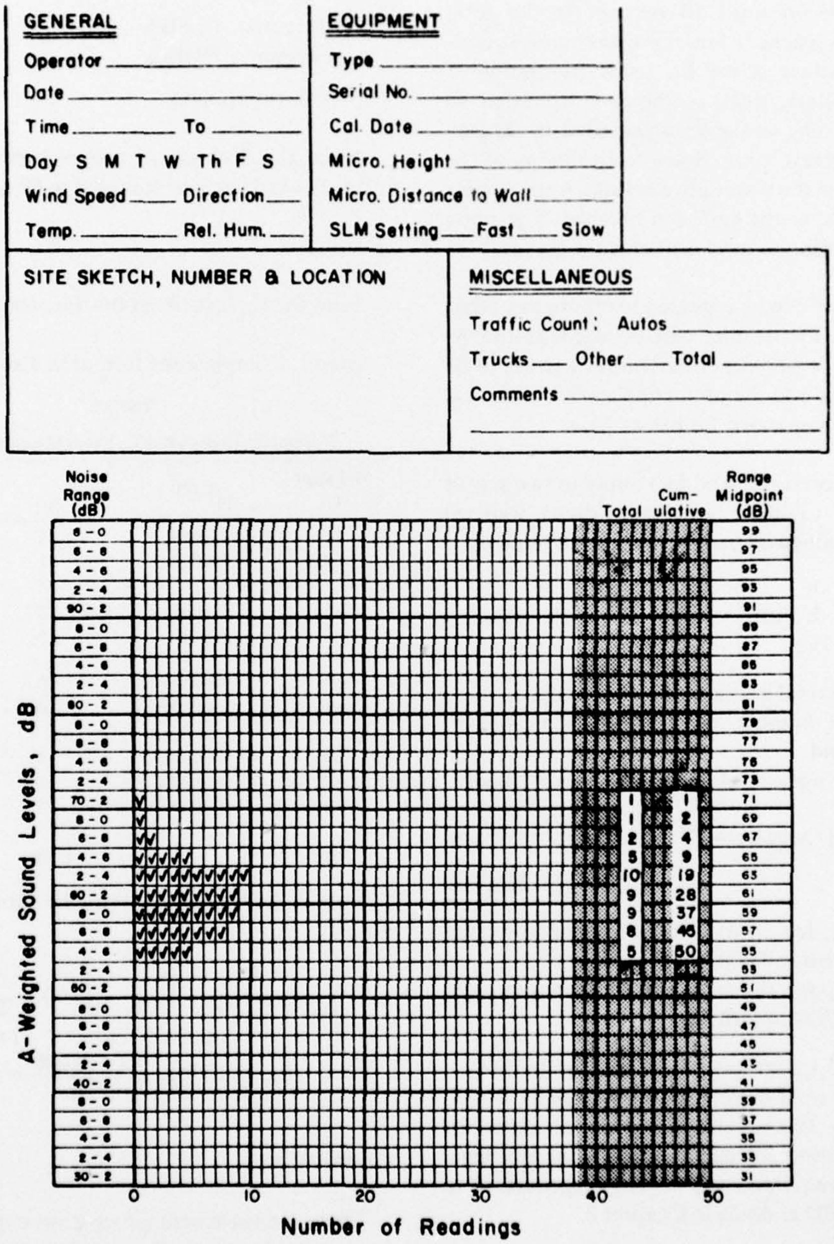


Figure E4. Noise survey data log. (From *Community Noise Monitoring—A Manual for Implementation.* Technical Report WR 76-8 [Wyle Laboratories, July 1976].)

The statistical levels apply to only the single-event sources and can be obtained by using the following processes:

For L_{10} (the level exceeded 10 percent of the time or the level exceeded by 10 percent of the sources), count down from the top of the tally sheet or use the cumulative column until 10 percent of the total count has been reached. The noise level corresponding to this number is the L_{10} level. Interpolate if necessary. Similarly, for L_{90} (the level exceeded 90 percent of the time or the level exceeded by 90 percent of the sources), count down from the top of the tally sheet or use the cumulative column until 90 percent of the total count has been reached. The noise level corresponding to this number is the L_{90} level.

The procedure can be repeated to obtain any other L_n parameter. The results can be used as the A-weighted noise level (AL) of individual sources to be inserted directly into the prediction models. (The L_{50} criterion is recommended for use as AL.)

The energy levels (L_{dn} and L_{eq}) apply to two sets of measurements (outdoor and multi-event sources) and can be obtained by using the equations below:

$$L_{eq} = 10 \log_{10} \sum_{i=1}^{n} S_i 10^{L_i/10} / \sum_{i=1} S_i \quad \text{dB} \quad \text{[Eq E1]}$$

where n = the total number of noise bands

S_i = the number of occurrences in the i^{th} band

L_i = the noise level representing the i^{th} band.

$$L_{dn} = 10 \log_{10} 1/24\,[15(10)^{L_d/10} + 9(10)^{(L_n+10/10)}]\text{dB} \quad \text{[Eq E2]}$$

where L_d = L_{eq} for all measurements taken during the day (0700-2200)

L_n = L_{eq} for all measurements taken at night (2200 and 0700).

The L_{eq} and L_{dn} values calculated for individual sources can be used directly in the Appendix D prediction models. The L_{eq} and L_{dn} values calculated for a general environment can be used to satisfy legal and technical requirements, to verify contours, or to conduct the NED analysis in Chapter 3.

Example

Find the L_{50} level from the data sheet in Figure E4.

Step 1. The L_{50} level is the level exceeded 50 percent of the time or the level exceeded by 50 percent of the number of occurrences. Since there is a total of 50 counts, L_{50} is determined from the 25^{th} count.

Step 2. Locate the 25th count and its corresponding noise level in Figure E4.

28 counts - 61 dBA
19 counts - 59 dBA

Step 3. Interpolate.

Since the 25th count occurs between 59 and 61 dBA, L_{50} can be approximated to 60 dBA.

Example

Find the L_{eq} level from the data sheet in Figure E4.

Step 1. Complete the format in Table E1.

Table E1

Format for Computing L_{eq} From Measurement Data

Midpoint L_i	$10^{L_i/10}$	S_i	$S_i \cdot 10^{L_i/10}$
71	12590000	1	1259 0000
69	7940000	1	794 0000
67	5010000	2	1002 0000
65	3160000	5	1580 0000
63	2000000	10	2000 0000
61	1260000	9	1134 0000
59	800000	9	720 0000
57	500000	8	400 0000
55	320000	5	160 0000
Total		Σ 50	Σ 9049 0000

Step 2. Compute L_{eq} from the format above and Eq E1:

$$L_{eq} = 10 \log_{10} \sum_{i=1}^{n} S_i \cdot 10^{L_i/10} / \sum_{i=1}^{n} S_i \ \text{dB[Eq E1]}$$

$$L_{eq} = 10 \log_{10} \frac{90{,}490{,}000}{50} = 62.6 \text{ dB}$$

Conclusions

These measurement procedures can only be used in simple situations. For detailed measurements of complex sources and/or long-term monitoring, the process becomes so complex that expert assistance is recommended.

APPENDIX F: ASSESSING VIBRATION

While structural vibration may be caused by airborne sound or groundborne waves, most problems can be traced to blast noise where the response is a side effect of the auditory stimulus. Here the effects of both these waves can usually be accounted for the C-weighted L_{dn} analysis (Appendix D). Nonetheless, it is sometimes necessary to separately assess the vibration caused by blasts as well as other sources.

While techniques for measuring, predicting, and assessing vibration are not as advanced as those for noise, this appendix presents the best available method to evaluate both the resultant human and structural response. Because of its complexity, this analysis should only be undertaken by personnel with strong scientific/engineering backgrounds. As more information in this area becomes available, it will be presented in future publications. Many concepts in this appendix are based on the work of CHABA.[47]

Measurement

Because of the multiple parameters, there is no universal prediction methodology for vibration. As a result, all assessments must be based on measurements. For continuous vibration environments, RMS (root mean square) acceleration levels should be measured along three orthogonal axes, one of which is normal to the surface of interest. The measurement should be taken on the floor, at the mid-span, or in the center of the room. In addition, the weighting in Figure F1 should be applied to the vibration signal to account for the dependence of human response on frequency. This electronic network only considers energy between 1 and 80 Hz.

For impulsive shock, the procedure is similar, except that the peak value (not the RMS value) is used.

Human Response Criteria[48]

Table F1 summarizes criteria to evaluate human response to vibration. It is compiled from existing and proposed standards and uses measurements obtained from the previous section. This table can be used in conjunction with Figure F2 to quantify the impact from excessive vibration. In this figure, the number of complaints per residential area roughly increases with peak acceleration according to:

$$\# = 20 \log K \qquad \text{[Eq F1]}$$

where # = the number of complaints
K = the ratio of peak acceleration to a reference of 0.1 m/sec².

If this concept is broadened by defining K as the ratio of actual vibration to the criteria in Table F1, a vibration weighting function can be defined by

$$V(K) = 20 \log K \qquad \text{[Eq F2]}$$

where V(K) = the vibration weighting function
K = the ratio of the actual acceleration to the recommended criterion in Table F1.

A quantitative description of the total vibrational impact of a project can now be obtained by multiplying the number of people exposed to each vibrational condition by the V(K) for that condition. Specifically,

$$VWP = \sum_{i=1}^{n} P_i V_i \qquad \text{[Eq F3]}$$

where VWP = vibration weighted population
V_i = vibration weighting for the i^{th} vibration increment
P_i = population exposed to the i^{th} vibration increment
n = number of increments.

Similarly, the average annoyance per person (VWP) can be computed by

$$\overline{VWP} = \sum_{i=1}^{n} P_i V_i / \sum_{i=1}^{n} P \qquad \text{[Eq F4]}$$

While VWP is only an abstract term, it represents an index similar to LWP and PHL (Chapter 2) in that it provides a practical measure of the vibration's effects. Changes in VWP can be used to evaluate various alternatives and actions; i.e., one project has twice as much impact as another, etc.

---

[47] *Guidelines for Preparing Environmental Impact Statements on Noise*, Draft Report of CHABA Working Group Number 69 (Committees on Hearing and Statistics, Feburary 1977).

[48] *Guidelines for Preparing Environmental Impact Statements on Noise*.

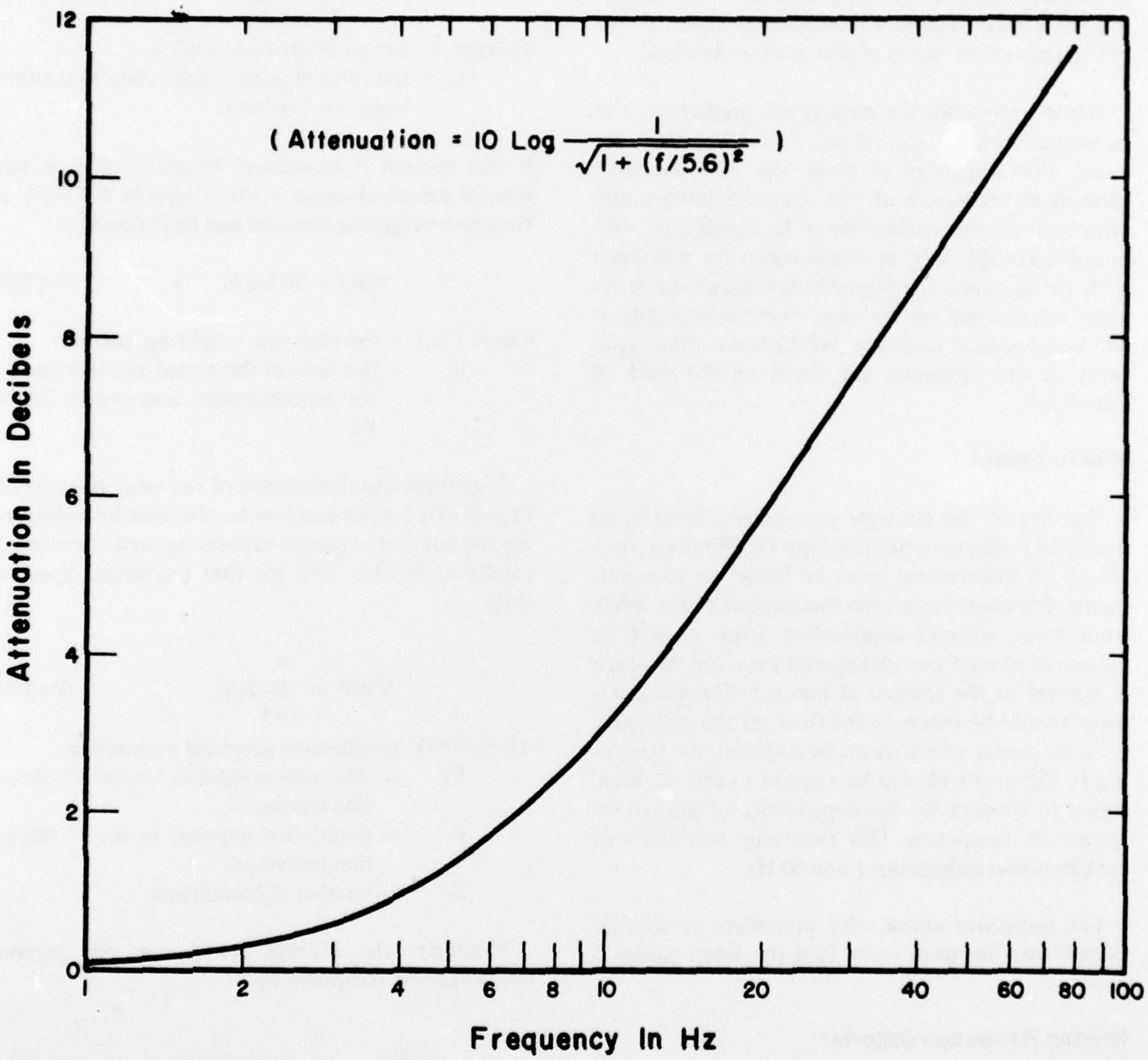


Figure F1. **Recommended frequency weighting of building vibration to account for human response. (From *Guidelines for Preparing Environmental Impact Statements on Noise,* Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)**

Table F1

Human Response Criteria for Vibration

(From *Guidelines for Preparing Environmental Impact Statements on Noise.* Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bio-acoustics, February 1977].)

		Complaint Criteria (m/sec²)	
Type of Place	**Time**	***Continuous or* Intermittent rms Acceleration**	**Impulsive Shock Excitation Peak Acceleration**
Hospital operating rooms and other such critical areas	Day*	.0036	.005
	Night	.0036	.005
Residential	Day	$\frac{.072}{\sqrt{t}}$	$\frac{.1}{\sqrt{N}}$
	Night	.005	.01
Office	Anytime	$\frac{.14}{\sqrt{t}}$	$\frac{.2}{\sqrt{N}}$
Factory and workshop	Anytime	$\frac{.28}{\sqrt{t}}$	$\frac{.4}{\sqrt{N}}$

*Daytime is 0700-2200 hours; nighttime is 2200-0700 hours.

t = time in seconds up to 100 seconds. Times greater than 100 seconds should use 100 seconds.

N = the number of discrete shock excitations that are 1 second or less in duration. For number of excitations greater than 100, use N = 100.

Example

Quantify in VWP the impact of a source which when measured at night has the following RMS acceleration values in various homes.

Level (L) m/sec²	**Number of homes**	**Number of people exposed**
.008	2	10
.01	1	3
.05	2	6

Step 1. From Table F1, the recommended criterion at night in residential areas is .005. Thus, from Eq F2

$$V(K) = 20 \log_{10}(L/.005) \qquad \text{[Eq F2]}$$

Step 2. Complete the format as shown in Table F2:

Table F2

Format for Computing VWP

Level (L) m/sec²	V(K)	People (P_i)	P_iV_i
.008	4	10	40
.01	6	3	18
.05	20	6	120
Total	ΣP_i	19	ΣP_iV_i 178

Step 3. Quantify the impact:

$$VWP = 178$$

$$\overline{VWP} = 178/19 = 9.4$$

These numbers can now be used to quantify the vibrational impact of this activity.

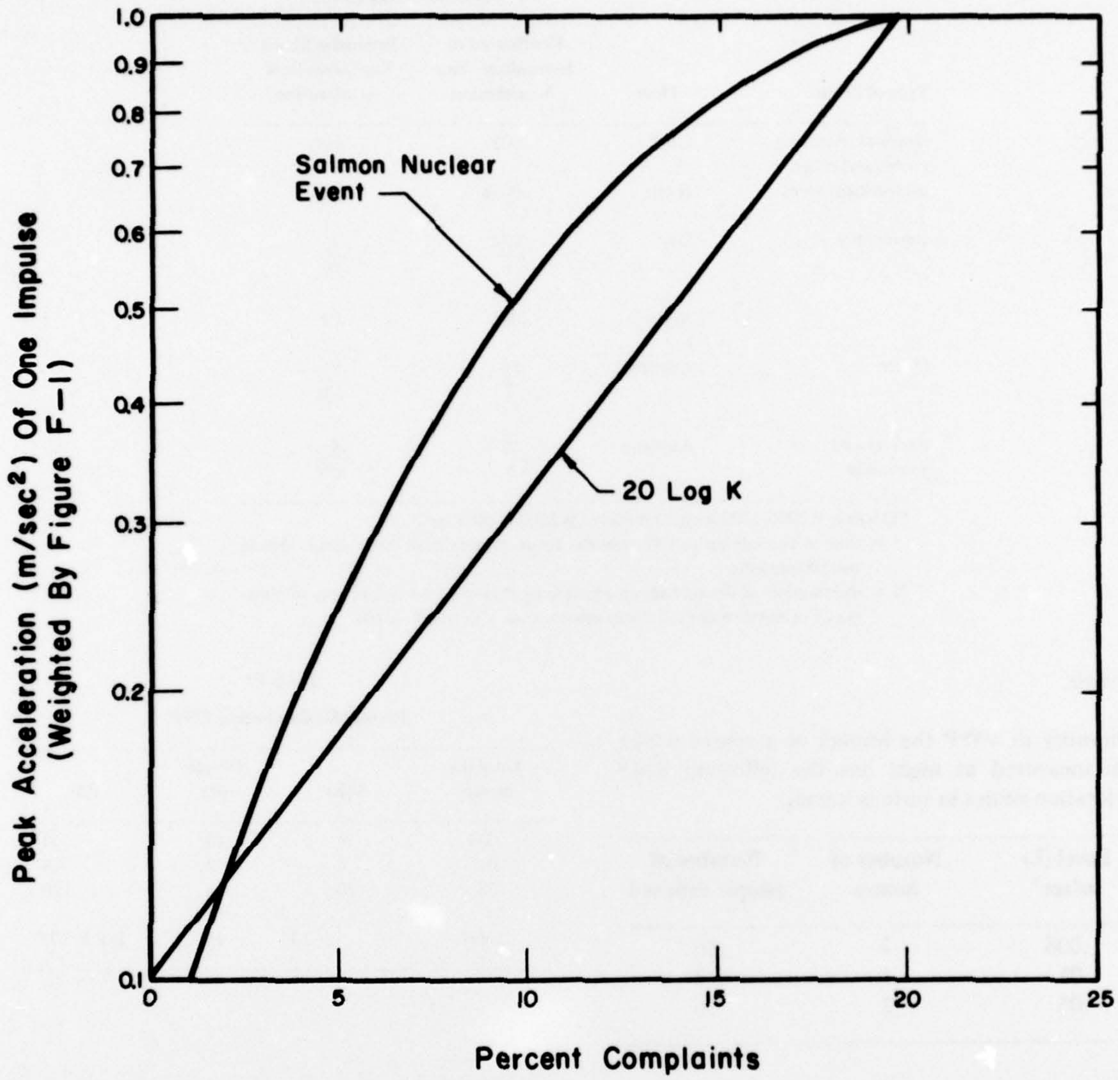


Figure F2. Percent complaints from one vibration exposure. (From *Guidelines for Preparing Environmental Impact Statements on Noise,* Draft Report of CHABA Working Group Number 69 [Committees on Hearing and Bioacoustics, February 1977].)

Structural Damage Criteria

Normally the parts of a structure most sensitive to airborne waves or overpressure are the windows, followed by plastered walls and ceilings. When the levels are high enough, these effects should be evaluated, as well as possible structural damage. The following procedures are presented:

Blast Noise/Artillery Fire[49]

For blast noise, window breakage in residential-type structures is expected to be negligible (less than 50 percent probability of even one broken pane) if the total weight (kilograms) of high explosives used in a single event is less than 40 R^3, where R is the distance in kilometers to the nearest *group* of residences. For explosive charges greater than this criterion, the peak overpressure should be predicted[50,51] and the number of broken windows estimated from:

$$Q = 4.2 \times 10^{-10} N (PK)^{2.78} \qquad \text{[Eq F5]}$$

where Q = statistical estimator for the number of "*average typical*" *broken panes*
N = number of people exposed, assuming 19 panes/person
PK = peak overpressure in pascals.

The quantity N can be obtained by drawing a contour around the source on land-use maps and counting homes within the contour. The radius of this contour, R, is defined by:

$$R = (\text{wt in kg}/40)^{1/3} \qquad \text{[Eq F6]}$$

Whenever the peak overpressure exceeds 140 dB, structural damage other than broken windows may occur and a statement to this effect should be included in the EIA/EIS.

[49]P. D. Schomer, R. J. Goff, and L. Little, *The Statistics of Amplitude and Spectrum of Blasts Propagated in the Atmosphere*, Technical Report N-13/ADA033475 (CERL, November 1976).

[50]P. D. Schomer, *Predicting Community Response to Blast Noise*, Technical Report E-17/AD# 773690 (CERL, December 1973).

[51]*The Statistics of Amplitude and Spectrum of Blasts Propagated in the Atmosphere.*

Continuous Sounds

For low- and medium-frequency sounds whose sound pressure levels exceed 130 dB, there is the possibility of structural damage due to excitation of structural resonances. While certain frequencies (such as 30 Hz for window breakage) might be of more concern than others, a reasonable estimate of possible structural damage is to regard all sound lasting more than 1 second above a sound pressure level of 130 dB (1 Hz to 1000 Hz) as potentially damaging.

General

It is recommended that an acceleration of 1 m/sec^2 be the general criterion with respect to structural damage for this category. In addition, since minor damage has occasionally been reported at levels as low as 0.5 m/sec^2, accelerations in this range (0.5 m/sec^2 to 1 m/sec^2) should also be regarded as potentially adverse. Finally, vibrations affecting ancient monuments or ruins should not have acceleration levels exceeding 0.05 m/sec^2. Higher noise exposures to such ancient structures should not be considered safe without a detailed structural analysis.

General Vibration Assessment Guidelines

While there is a general lack of data for assessing the severity of impact when the vibration criteria (both human and structural) are exceeded, it is recommended that the information below be included in the EIA/EIS.

Number of people exposed to vibration levels above the complaint criteria in Table F1.

Number of potential broken windows from Eq F5.

Number of structures exposed to potentially damaging acceleration levels of 1 m/sec^2 and 0.5 m/sec^2.

To obtain this information, the following steps are recommended.

Step 1. Prepare land-use maps of the area in question, using the procedures listed in Chapters 2 and 3.

Step 2. Using the same scale as the land-use map, draw on a transparent sheet the following contours

(which can be obtained either by prediction or measurement):

1. For probable structural damage—1 m/sec²

2. For possible structural damage—0.5 m/sec²

3. Annoyance criteria (Table F1)

4. For a possible broken window—the quantity R (Eq F6)

Step 3. Overlap the contour onto the land-use map.

Step 4. Tabulate and list the following in the EIA/EIS:

1. Number of structures where exposure level exceeds 1 m/sec²

2. Number of structures where exposure level is between 0.5 and 1.0 m/sec²

3. Number of people within R

4. Number of people exposed to criteria in Table F1.

Step 5. Compute and list the following in the EIA/EIS:

1. VWP and $\overline{VWP}$ from data in Step 4 (include in appendix of EIA/EIS)

2. The number of "expected" broken windows from R and Eq F5 (Point 3 of EIS guidelines).

END

CERL DISTRIBUTION

Chief of Engineers
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-FE
ATTN: DAEN-FEB-N
ATTN: DAEN-FEE-A
ATTN: DAEN-CWZ-R (3)
ATTN: DAEN-CWR-R (2)
ATTN: DAEN-MCE-P
ATTN: DAEN-MCE-D (10)
ATTN: DAEN-MCZ-S (2)
ATTN: DAEN-RDL
ATTN: DAEN-ZCE (10)
Dept of the Army
WASH DC 20314

US Military Academy
ATTN: Dept of Mechanics
ATTN: Library
West Point, NY 10996

Learning Resources Center
US Army Engineer School
ATTN: ATSEN-DT-LD (2)
ATTN: Archives Section/Bldg 270
ATTN: Kingman Bldg, Library
Ft Belvoir, VA 22060

Assistant Chief of Engineers
Dept of the Army
Rm 1E668, Pentagon
WASH DC 20310

The Army Library (ANRAL-R)
ATTN: Army Studies Section
Room 1A518, The Pentagon
WASH DC 20310

Commander, TRADOC
Office of the Engineer
ATTN: ATEN
Ft Monroe, VA 23651

Plastics Technical Evaluation
Center
ATTN: SMUPA-VP3
Picatinny Arsenal
Dover, NJ 07801

Dept of the Army
US Army Human Engr Lab
ATTN: AMZHE/J. D. Weisz
Aberdeen Proving Ground, MD 21005

Commander
US Army Medical Environmental
Engr Research Unit (2)
Aberdeen Proving Ground, MD 21005

Commander
Picatinny Arsenal
ATTN: SMUPA-MT-C/Foreston (2)
Dover, NJ 07801

Each US Army Engr Dist
ATTN: Library
ATTN: Regulatory Functions
ATTN: Environmental Resources
ATTN: Military Planning Sections*
*Kansas City, Omaha, Baltimore, New York, Norfolk, Alaska, Mobile, Savannah, Los Angeles, Sacramento, Fort Worth

US Army Engr Div, North Central
ATTN: Chief, Engr Div
536 S. Clarke St
Chicago, IL 60605

Indicated Facilities listed in Pam 210-1
ATTN: Facility Engr/Environmental Office

Director
USA Cold Regions Research Engineering
Laboratory
PO Box 282
Hanover, NH 03755

Director, USA-WES
ATTN: MESL
ATTN: EEL
ATTN: Library
PO Box 631
Vicksburg, MS 39181

Commander
ATTN: HQ, HSCM-R
Ft Sam Houston, TX 78234

ENV Mgmt Committee
Army Logistics Mgmt Center
ATTN: DRXMC-MR-I (5)
Ft Lee, VA 23801

Director
HQ Defense Logistics Agency
ATTN: DLA-OSC
ATTN: DLA-WS (4)
Cameron Station
Alexandria, VA 22314

DFAE/Juan H. Diaz (3)
193d Inf BDE (CZ)
APO New York 09834

Commander
ATTN: Facility Engr/Env Office
Ft Buchanan, Puerto Rico 00934

HQ DARCOM
ATTN: DRX-PA-E
5001 Eisenhower Ave
Alexandria, VA 22333

Institute for Water Resources
Kingman Bulding
ATTN: J. Delli Priscoli
Ft Belvoir, VA 22060

Commander
ATTN: Facility Engr/Env Office
Ft Richardson, AK 99505

Commander
ATTN: Facility Engr/Env Office
Schofield Barracks, HI 96857

Commander
ATTN: Facility Engr/Env Office
Ft Wainwright, AK 99703

Commander
ATTN: Facility Engr/Env Office
Ft Shafter, HI 96858

Commander
ATTN: Facility Engr/Env Office
Ft Greely
APO Seattle, WA 98733

Commanding General
US Army Engr Command, Europe
APO New, NY 09403

US Army R&S Group (Eur)
ATTN: AMXSN-E-RM/R. Quattrone
Box 65
FPO New York 09510

Commanding General
US Army Forces Command
ATTN: AFEN-EQ (4)
Ft McPherson, GA 30330

Aberdeen Proving Ground
ATTN: STEAP
Aberdeen Proving Ground, MD 21005

Armament Materiel Readiness Command
ATTN: DRSAR-CG
Rock Island, IL 61201

Armament R&D Command
ATTN: DRDAR-CG
Dover, NJ 07801

Aviation Systems Command
ATTN: DRSAV-G
PO Box 209
St Louis, MO 63166

Depot System Command
ATTN: DRSDS
Chambersburg, PA 17201

Commander
Dugway Proving Ground
ATTN: STEEP
Ft Huachuca, AZ 85613

Electronics Command
ATTN: DRSEL-CG
Ft Monmouth, NJ 07703

Harry Diamond Labs
ATTN: DRXDO-CO
2800 Powder Mill Rd
Adelphi, MD 20783

Installations and Services Activities
ATTN: DRCIS-RI
Rock Island, IL 61201

Missile Materiel Readiness Command
ATTN: DRSMI
Redstone Arsenal, AL 35809

Missile R&D Command
ATTN: DRDMI-X
Redstone Arsenal, AL 35809

Mobility Equipment R&D Command
ATTN: DRDME
Ft Belvoir, VA 22060

Natick R&D Command
ATTN: DRDNA
Kansas St
Natick, MA 01760

Tank-Automotive Materiel Readiness Command
ATTN: DRSTA-CG
Warren, MI 48090

Tank-Automotive R&D Command
ATTN: DRDTA-NG
Warren, MI 48090

Test and Evaluation Command
ATTN: DRSTE
Aberdeen Proving Ground, MD 21005

Troop Support Command
ATTN: DRSTS
4300 Goodfellow Blvd
St Louis, MO 63120

Dugway Proving Ground
ATTN: STEDP
Dugway, UT 84022

AF/PREE
Bolling AFB, DC 20332

AF/RDXT
WASH DC 20330

Chief, Civil Engr Research Div
Air Force Weapons Lab
ATTN: DE
Kirtland AFB, NM 87117

Commander
ATTN: AFEC-EVP (3)
Tyndall AFB, FL 32403

AF/PREVX
ATTN: LT COL William R. Sims
Pentagon
WASH DC 20330

Chief, Naval Operations
ATTN: The Library
Dept of the Navy
WASH DC 20360

US Naval Academy
Political Sicence Dept
ATTN: Prof Skove
ATTN: Prof Cochran
Annapolis, MD 21402

Chief, Construction and Maintenance
Standards Branch, AAS-580
Federal Aviation Administration
800 Independence Ave, SW
WASH DC 20591

Transportation Research Board
National Research Council (3)
2101 Constitution Ave
WASH DC 20418

Office of Management Svc, MS 110 - FAA
800 Independence Ave, SW
WASH DC 20553

Dept Transportation Library
Acquisitions Section (SR) TAD-491.1
400 7th St, SW
WASH DC 20590

Library of Congress
Exchange and Gift Division
ATTN: Federal Documents Section (2)
WASH DC 20540

Superintendent of Documents
Div of Public Documents
ATTN: Library (2)
US Govt Printing Office
WASH DC 20402

Institute of Defense Analysis
400 Army-Navy Drive
Arlington, VA 22202

Director
Veterans Administration
Environmental Planning Division (088C)
810 Vermont Ave, NW
WASH DC 20420

Commander
USA Intelligence and Security Command
ATTN: ILOG-IF
Arlington Hall Station
Arlington, VA 22212

Environmental Protection Agency (EPA)
ATTN: International Environmental Referral
Center
ATTN: Office of Federal Activities/P. Cook
401 M Street, SW
WASH DC 20460

Defense Documentation Center
ATTN: TCA (12)
Cameron Station
Alexandria, VA 22314

Engineering Societies Library
345 East 47th Street
New York, NY 10017

Ralph Liss Associates
1800 Peachtree Road, NW
Atlanta, GA 30309

Director
Defense Logistics Agency
Defense Property Disposal Service
ATTN: DPDS-OP
Federal Center
Battle Creek, MI 49016

BMD Corporation
7915 Jones Branch Drive
McClellan, VA 22101

Mitre Corporation
Metrek Division
1820 Dolly Madison Blvd
McLean, VA 22101

Stanford Research Institute
ATTN: Marilyn Duffey-Armstrong (3)
333 Ravenswood Ave
Menlo Park, CA 94025

Brookhaven National Laboratory
ATTN: Sam Morris
Upton L.I., NY 11973

Goff, Richard J
Environmental noise impact analysis for Army military activities : user manual / by R. J. Goff and E. W. Novak. -- Champaign, Ill. : Construction Engineering Research Laboratory ; Springfield, Va. : for sale by National Technical Information Service 1977.
118 p. : ill. ; 27 cm. -- (Technical report - Construction Engineering Research Laboratory ; N-30)

1. Noise pollution. 2. Environmental impact statements. I. Novak, Edward W. II. U.S. Construction Engineering Research Laboratory. III. Title. IV. Series: U.S. Construction Engineering Research Laboratory. Technical report ; N-30.

DEPARTMENT OF THE ARMY
CONSTRUCTION ENGINEERING RESEARCH LABORATORY
P. O. BOX 4005
CHAMPAIGN, ILLINOIS 61820

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300

POSTAGE AND FEES PAID
DEPARTMENT OF THE ARMY
DOD - 314

U.S.MAIL

THIRD CLASS